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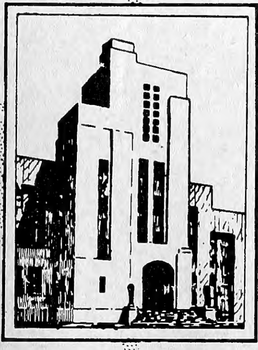

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A RADIO CONTROL AND POWERING SYSTEM FOR FREE-RUNNING MODELS OF SURFACE SHIPS

by

C.W. Hoffman

INDUSTRIAL DEPARTMENT

RESEARCH AND DEVELOPMENT REPORT

February 1960

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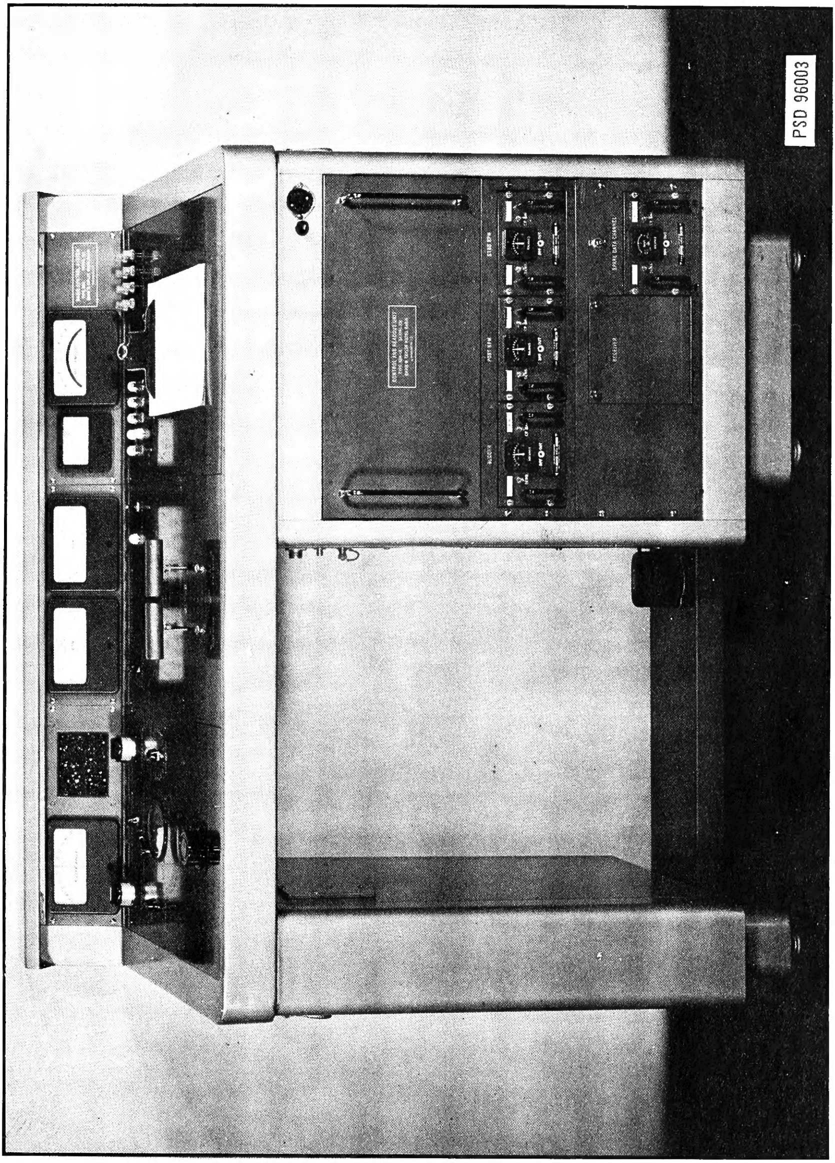
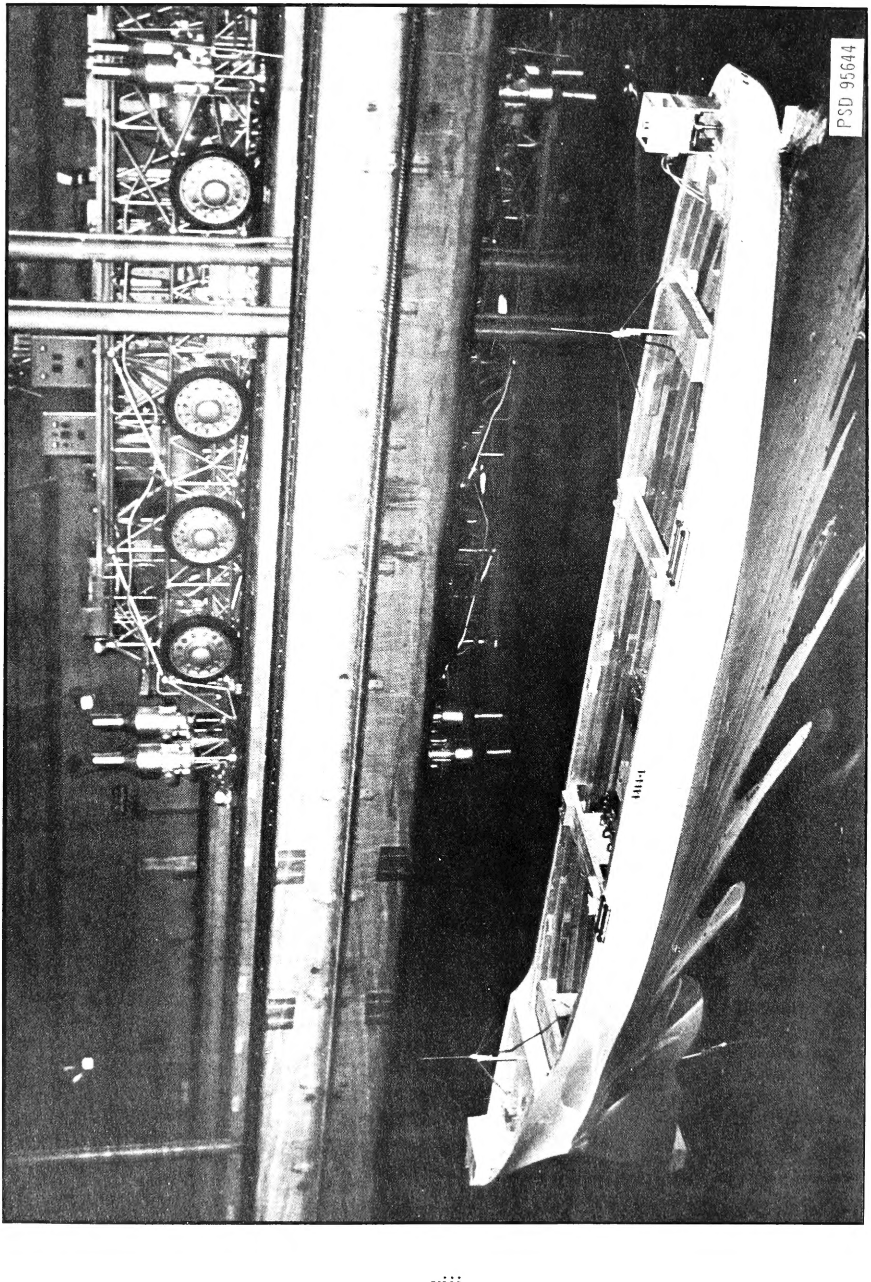


Radio Control Console, Type 304



Radio Control System Installed in 1/24-Scale Model of Mariner-Class Hull

ABSTRACT

This report describes a radio-control system for free-running models of surface ships. The system is designed for use in models ranging from approximately 15 to 30 feet in length and is arranged so that it may be used with single or multiscrew propulsion systems. A proportional rudder-control channel and two proportional propulsion-control channels are provided. Rudder position, rudder running time, and propulsion shaft rpm are indicated on the console to guide the operator in controlling the model. The system is powered by long-life rechargeable nickel-cadmium batteries.

This report includes a brief review of the engineering study, and describes the complete system. Installation, operation and maintenance instructions, with photographs and schematic diagrams, are included.

INTRODUCTION

Free-running self-powered models of surface ships are used by the TMB Hydromechanics Laboratory for tests to determine and predict maneuverability characteristics of the ship. In the past these tests have been conducted in the J-shaped end of the main TMB towing tank. Power and control circuits to the model have been carried through a multiconductor cable or "drop-cord," supported by a movable boom which is manually operated to suspend the "drop-cord" more or less directly over the model during the test maneuver.

During the course of design of the new TMB Maneuvering and Seakeeping Facility now nearing completion, work was initiated to develop requirements and specifications for a completely free-running self-powered radio-controlled model system. Since the maneuvering basin in this facility is about 240 by 360 feet, it was felt that a moving boom and drop-cord would be impractical over an area of this size. The functional requirements[1] for the radio-control system were developed by the Stability and Control Division of the Hydromechanics Laboratory. The Instrumentation Division and the Facilities Division of the Industrial Department jointly conducted a feasibility and preliminary design study[2] of a system to meet these requirements and subsequently designed and constructed the complete control and powering system.

[1]References are listed on page VI-1.

PART I – ENGINEERING STUDY

1. THE PROBLEM

The functional requirements for a radio-control system[1] called for a system for use in 10- to 30-foot models of surface ships. The total displacement for these models ranged from 130 pounds for 10-foot models to approximately 2 tons for some of the large models. The control system was to provide two channels of step- or full-proportional control for propulsion motor drive, with capabilities of reversing either or both motors, and a third channel for step or proportional control of one or two rudders. The original propulsion requirement of 2 hp per channel was later revised to 3 hp per channel. Rudder torque requirements ranged from zero to 100 inch-pounds per rudder at velocities of from 4 to 40 degrees per second. It was desired that the overall accuracy and stability of the system be better then ± 1 percent for each control function. The design of the system was to be flexible enough to permit the equipment to be used in as wide a range of hull types as possible and for a wide variety of model tests.

The primary problems in the design of the system were: (1) the requirements for very high accuracy and stability in both steering and speed control, (2) the need for large amounts of propulsion power during 2- to 4-minute test runs, and (3) the limitations on weight of the equipment, to permit it to be used in small models.

There were several minor requirements, such as having an indication of model-control behavior at the console, and providing a readout system which could be expanded to handle additional data channels. These did not constitute any serious problem, however.

2. THE APPROACH

2.1 CONTROL AND READOUT EQUIPMENT

The first problem to be solved was the selection of suitable radio-control and data-handling equipment, and many types of radio-control and telemetering equipment were considered. It appeared at first that one of the military types of drone-control equipment would be suitable. Several types of these systems were investigated, ranging from the simple "beep" type to systems containing several proportional and on-off channels. A digital data-transmission system was also considered. This had been designed for the control of large drone boats and was of relatively high accuracy and stability. There were specially designed actuators for use with some of these systems; however, they were not available with suitable run-in rates and torque capabilities. None of these systems were considered to come near enough to the requirements of the TMB radio-control system.

Attention was next focused on the use of standard telemetering equipment for both the control and readout equipment. There are a wide variety of telemetering methods such as

FM (frequency modulation), PAM (pulse amplitude modulation), PWM or PDM (pulse width or duration modulation), and PCM (pulse code modulation). The PCM systems were considered highly desirable for this application because of their high accuracy, but the equipment was rather large and complex for use as control equipment. The other types of pulse systems had little to offer in accuracy over the FM systems, and had the disadvantage that such systems are somewhat subject to loss of synchronization if the radio signal is momentarily lost.

Investigation of the FM systems disclosed that system accuracies of better than 1 percent should be possible if components were carefully selected and used under limited environmental conditions. This type of system could also be expanded very easily if additional data channels were required at a later date.

Subcarrier oscillators and discriminators were commercially available with stability and accuracy within ± 1/4 percent or better. Subcarrier oscillators and phase-modulated transmitters were generally available in subminiature form; however, at the time there had not been a large demand for subminiaturized discriminators and receivers since this is normally ground-based equipment, and for this reason, only a few types were available. Transistorized subcarrier equipment was becoming available, but the stability and accuracy were not comparable to the best subminiature vacuum tube gear.

The final decision was to use vacuum tube FM-PM telemetering gear for both the control and readout portions of the system. It was realized that this equipment would be too large for use in 10- to 15-foot models. However, since a single system could not possibly meet the conflicting weight requirements for small models and the servo and propulsion power requirements for large models, it was considered desirable to have a system suitable for use in the models of the sizes most frequently used. Although commercial subcarrier circuitry could also have been used for control of on-off functions, such as fail-safe and propulsion motor reversing, it was felt that low-frequency tone circuitry would be more suitable for these purposes. This would permit a great saving of weight. By using high-Q circuits it would be possible to handle several on-off channels in the frequency band occupied by one standard FM subcarrier channel. Further reductions in the weight of this equipment could be gained by the use of electromechanical oscillator controls and frequency detectors which eliminated the need for large high-Q inductors in the frequency-determining circuitry.

In order to maintain as high a degree of stability and accuracy as possible, the use of regulated power supplies was considered mandatory. Vacuum tube regulators could be used for the console circuitry, but to keep the power drain in the model equipment low, transistorized regulators were required. These regulators have an efficiency of about 80 percent as compared to the 25-percent efficiency, and greater size and weight of vacuum tube supplies.

There were no servo actuators commercially available meeting the variable-speed and torque requirements for the rudder servo. A unit of special design was required to meet all of the system requirements including compatibility with existing dynamometers. To meet the

variable-speed requirement with standard types of servo equipment would have required the use of a relatively large motor having good speed regulation and a variable-ratio gear box for changing speed. To eliminate the need for a large motor and variable-ratio gear box, a special servo was devised which accomplished these functions by means of electrical feedback.

2.2 POWER AND POWER CONTROL EQUIPMENT

A great deal of study went into the selection of a drive system and its components. Choice of a prime mover was quickly limited to a storage battery because its energy per pound compares favorably to compressed gasses, wound springs, etc.; because batteries have little effect on the model and its contents; and because electricity is easy to control.

Four commercially available types of batteries were considered: the lead-acid, silver-zinc, nickel-cadmium, and nickel-iron. Weight, terminal voltage stability, and battery cost per test run eliminated all but the nickel-cadmium battery. The nickel-cadmium battery weighs less than one-third the weight of an equivalent lead-acid type, it can be charged or discharged at very high current rates, and it has an extremely long life of 10 to 15 years. Its terminal voltage curve was not flat like that of the silver-zinc battery, but was much better than that of the lead-acid battery.

When the prime mover had been selected, consideration was given to propulsion motor requirements. Use of a 100-cell battery, with cell switching and voltage interpolating, was eliminated because of certain disadvantages, which included the inability of the system to restrict the voltage change to 1 percent during a test run. The only way in which the speed accuracy requirement could be met was to use a feedback-regulated variable-voltage motor-generator set. Since specifications called for two independently controlled sources, two motor-generator sets are provided. A source of 400-cycle power for instrumentation was also specified, hence an alternator set is provided.

To keep the weight of the rotating equipment to a minimum, fairly high rotational speeds were dictated. However, this introduced the possibility of objectionable precessional forces acting while the model was maneuvering or being tested in waves. The rotation of the pair of motor-generator sets, or of one motor-generator set and the alternator set, are opposite one another so that gyroscopic effects are partially canceled.

A further advantage of motor-generator sets is that their drive motors will remain running once started. The propulsion motors are easily started and stopped by controlling the generator voltage. Hence, no starting equipment is needed for the propulsion motors, and the starting equipment for the motor-generator and alternator sets is not located in the model.

To meet the speed accuracy requirement, feedback regulation is required. Normally, the speed of a motor is controlled by the use of a tachometer generator and a speed reference voltage. In this application it is desired that the speed of the motors be constant within 1 percent during the approach part of the run, but be permitted to change when the load on the propellers varies, as in turns. Furthermore, series propulsion motors were specified, which

is contrary to the usual speed regulation practice. Therefore, the best answer to these conflicting requirements of constant speed under one set of conditions and changing speed under another set of conditions is regulation of the voltage supplied to the motor terminals. This type of regulation is analogous to a relatively unlimited supply of steam, maintained at a constant pressure, being delivered to a ship's turbine during maneuvers. Stepless control of the generator voltage throughout its entire range is permitted rather simply by voltage feedback regulation. Thus, an operator can match the carriage speed quite easily by means of the proportional radio-control circuitry.

It is phsically impossible, within the weight limitations, to have sufficient battery capacity for several hours operation between charges. A choice had to be made between changing batteries frequently or charging the battery between test runs without removing it from the model. The latter choice permits testing indefinitely with no more lost time between runs than that normally taken to prepare for the next run. Since motor-generator sets were selected, a lower voltage battery was permissible. Using the nickel-cadmium battery and charging it after each run permits the use of a lower capacity and, therefore, lighter battery. The charger selected is so designed that it can practically recharge the battery in about 8 minutes and simultaneously supply the power required to keep the generator sets turning over and to keep all electronic equipment warmed up, thus minimizing drift yet imposing no drain on the battery.

Reduced voltage starting of motor-generator and alternator-set drive motors is mandatory. In order to keep the amount of equipment in the model to a minimum, the bulk of the starting equipment is mounted on the charger. Plug-in connections to the model are made and once the generators are started, running contactors located in the model "seal in" and keep the sets running whether the power is being supplied from the battery or from the battery charger. However, if the source of power is interrupted or if the voltage falls 20 percent below normal, the contactors will open and it is necessary to go through the normal starting sequence to resume operation.

Because there is a possibility of losing control of the generated voltage through malfunctioning of one of the several links in the control system, a fail-safe provision is provided through a tone-controlled contact in the running-contactor coil-control circuit. This tone-controlled contact will open if there is any failure or intentional interruption in the radio linkage.

3. SPECIFICATIONS

The original specifications were set up as a result of the engineering study.[2] Subsequent conferences disclosed the desirability for making several modifications to the specifications. The only major modification was an increase in the power output of the propulsion system from 2 hp to 3 hp per channel. This was done to provide greater system flexibility and in anticipation of greater power requirements for future models.

The following specifications have been condensed from the original and include all pertinent subsequent changes. The weight of the total model-borne portion of the system compares favorably with the requirements of the original specification. Some of the chassis dimensions were increased but it was felt that this could be tolerated in the interest of reduced manufacturing costs and increased accessibility for maintenance.

3.1 CONTROL AND POWERING CIRCUITS

3.1.1 Rudder Channel

Steering Controls

Preset – Port and starboard rudder angles of zero to 45 degrees preset on multiturn dials plus a selector switch to be used by the operator to select either of these preset angles or zero degrees.

Wheel – Continuous control 45–0–45 degrees.

Step – 5-degree steps, 45–0–45 degrees.

External Programming – An oscillator or function generator to be used to program the motion of the rudder.

Rudder Servo

Input signal –

Radio control – 8–0–8 volts

Wire control* – 5000-ohm potentiometer, excitation voltage supplied by the servo system.

Range – 50–0–50 degrees

Run-in Rate

Standard circuit – Approximately 56 degrees per second for step changes in command signal, no-load.

Velocity stabilized circuit – 0–40 degrees per second, no-load.

Maximum running torque –

Standard circuit – 200 inch-pounds

Velocity stabilized circuit – 0–100 inch-pounds at 8–40 degrees per second, 0–200 inch-pounds at 4–20 degrees per second.

Positioning accuracy –

Radio control – ± 0.4 degree or better

Wire control – ± 0.2 degree or better

Position error due to loading – less than 0.15 degree for 200 inch-pound load change.

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*The servo amplifier has been designed for use in either wire or radio-controlled systems.

3.1.2 Propulsion Channels (2 identical channels)

Type – Proportional control of voltage to series-wound propulsion motors.

Controls – Lever type, zero to full power, forward or reverse.

Output voltage – 0–150 or 0–300 volts for full range of control lever. (Range switch in model equipment.)

Output current – 10 amperes maximum (rated).

Output power – 3000 watts maximum at low-duty cycle.

Stability – Hold selected output voltage to better than ± 1 percent for (1) Battery voltages between 1.3 volts per cell (full charge) and 0.8 volts per cell at end of run, (2) Changes in load from half load to full load.

Propulsion motor reversing – Automatic with operation of control lever by reversing armature connections.

Propulsion motors – Not supplied, 0–3 hp, 0–300 volts, series wound.

3.1.3 Model Powering Equipment

Motor-alternator – 115-volt 3-phase 750-volt-ampere output, 2-percent frequency regulation, continuous duty.

Batteries – 10-ampere-hour and 40-ampere-hour nickel-cadmium batteries, 34 cells per unit.

Battery charger – Charging rate adjustable up to 300 amperes at 49 volts d. c. Input – 3-phase 600 volts at 60 cycles or 3-phase 480 volts when used with auxiliary autotransformer.

3.1.4 Spare Control Channel

Type – ON-OFF control through radio link.

Control – Toggle switch on power control panel.

Contacts – Single pole – double throw rated at 1 ampere at 24 volts d. c. or 115 volts a. c.

Operate time – 0.1 second maximum.

3.2 READOUT CIRCUITS

3.2.1 Rudder Channel

Rudder position (analog)

Range – 45–0–45 degrees

Accuracy

Console indicator – ± 1.5 percent of full scale

Current output – ± 0.75 percent of full scale

Stability – Less than 0.25-degree drift per hour after warmup.

Output current – ± 1 milliampere into a 3000-ohm load.

Rudder position (digital)

Full equipment not furnished.

Range – 45–0–45 degrees

Accuracy

Console indicator – ± 1.5 percent of full scale.

Pulse output – ± 0.1 percent of full scale.

Output – Rectangular wave, 10 cycles per second per degree of rudder offset; relay contact closure for indication of direction.

Rudder running time

Indicator – Resettable electric clock on console.

Accuracy – ± 0.1 second.

3.2.2 Propulsion Channels (2 identical channels)

Console indicator

Range – 0–1500 or 0–3000 rpm

Accuracy – ± 1.5 percent of full scale

Calibration – Internal with 60-cycle power line reference.

Output –

Type of circuit – Rectangular wave to drive digital counter.

Amplitude – 25 volts into 600-ohm load.

Frequency – 10 cycles per revolution of propulsion shaft.

Accuracy – May be measured to the nearest tenth of a revolution with readings taken over any desired period of time.

3.2.3 Spare Data Channel

Frequency response – Depends on subcarrier channel used.

Accuracy –

Console indicator – ± 1.5 percent of full scale

Output current – ± 0.75 percent of full scale plus transducer errors.

Output current — $\pm$ 1 milliampere into a 3000-ohm load.

Stability — Less than 0.25 percent of full-scale drift per hour after warmup.

3.2.4 Spare ON-OFF Channel

Control — Contact closure in model.

Output — Relay contacts in console.

Contacts — Single pole — double throw rated at 1 ampere at 24 volts d. c. or 115 volts a. c.

Operate time — 0.1 second maximum.

3.3 RADIO LINKS

3.3.1 Transmitters

Type — Crystal-controlled, phase-modulated

Frequency range — 215-235 mc

Power output — 4.5 watts maximum.

3.3.2 Receivers

Type — Crystal-controlled, double-conversion superheterodyne

Frequency range — 215—235 mc

Sensitivity — 8 microvolts signal produces 20 db quieting.

Antennas — Omnidirectional, ground plane.

3.4 SIZES AND WEIGHTS OF MODEL EQUIPMENT

The following tables show the actual weight of complete typical systems and the sizes and weights of individual components and cables.

TABLE 1

Total Weight of Model Equipment under Typical Operating Conditions*

Item No.	Equipment	Weight lb
1	1 or 2 screws, small battery, with readout	292
2	1 or 2 screws, small battery, with readout, protective covers removed	283
3	1 or 2 screws, small battery, without readout, protective covers removed	261
4	2 or 4 screws, large battery, with readout	477
5	2 or 4 screws, large battery, with readout, protective covers removed	469
6	2 or 4 screws, large battery, without readout, protective covers removed	443

*Weight of propulsion motors is not included.

TABLE 2

Power Input, Chassis Dimensions, and Weight of Model Components

Model Components	Input watts	Dimensions inches			Weight	
		L	W	H	lb	oz
Antenna		16	16	16		7
Receiver		11 1/2	5 3/4	4 1/2	7	13
Receiver and Demodulator Power Unit	160					
with cover		13 5/8	5	8 1/2	23	
without cover		13 5/8	5	7 1/2	20	10
Demodulator Unit						
1 propulsion channel		16	11 1/2	8	28	11
2 propulsion channels		16	11 1/2	8	35	11
Servo Amplifier	190					
with cover		12	10 1/4	9	17	8
without cover		12	10 1/4	7 1/2	14	6
Servo Unit						
with dynamometer adapter		8 3/4	7	12 1/2	25	8
without dynamometer adapter		8 3/4	7	12	17	9
Dynamometer Adapter for 2nd Rudder		6 1/4	5	3*	5	10
Rudder Shaft Coupler					1	
Error Regulator	90	10	8	3 1/4	6	7
Motor-Generator and Control Unit		15	7 3/4	15 3/4	69	
Motor-Alternator and Control Unit		13	5 1/4	13	32	
10-Ampere-Hour Battery		21 1/4	6 1/2	7 1/4	54	
40-Ampere-Hour Battery		28	11 1/4	11	153	
RPM Pickup (including cable)		3 1/2	2	2 3/4	1	1
Readout Unit	65					
with cover		12	10 1/4	9	24	3
without cover		12	10 1/4	8	21	1

*Plus shaft and dynamometer.

TABLE 3

Weight and Length of Model Cables

Cable No.	Model Cables	Length ft	Weight lb	Weight oz
1	Antenna to Receiver or Transmitter	6		5
2	Receiver to Demodulator Rack	9		5
3	Power Unit to Receiver	6		8
4	Power Unit to Demodulator Rack	5 1/2	1	2
5	Demodulator Rack to Servo Amplifier	12		9
6	Servo Amplifier to Servo Unit	6	1	3
7	Demodulator Rack to Motor-Generator	6		15
8	Motor-Generator to Error Regulator	4		12
9	Motor-Generator to Propulsion Motor	Note 1		
10	Battery to Motor-Generator	3 1/3	Note 2	
11	Battery to Motor-Alternator	4	Note 3	
12	Demodulator Rack to Motor-Alternator	10		8
13S	Servo Unit to Readout Unit (short)	6		14
13L	Servo Unit to Readout Unit (long)	14	1	8
14	RPM Pickup to Readout Unit	3 1/2		
15	115-Volt Line (3-phase)	10		10
16	115-Volt Line (1-phase)	10		10

Note 1 — Length and weight depend on model powering equipment.

Note 2 — Included in weight of motor-generator.

Note 3 — Included in weight of motor-alternator.

PART II – SYSTEM DESIGN

1. DISCUSSION

This portion of the report describes the complete system in a functional breakdown. The radio frequency and subcarrier portions of the system use standard telemetering components for the proportional control and readout functions. Potentiometer-controlled subcarrier oscillators are used for all proportional channels except the rpm readout channels which use reactance-controlled oscillators. Miniature subcarrier discriminators* are used in the receiving circuitry for separation of proportional signals. Low-frequency tone generators and detectors of the electromechanical type are used for the remote control of all on-off functions such as power control and propulsion motor reversing.

Power for all model equipment is furnished by nickel-cadmium batteries which may be rapidly recharged between trial runs. The widely varying battery voltage is applied to a governor-controlled motor-alternator which supplies 400-cycle instrumentation power and to one or two motor-generators for control of propulsion power. The motor-alternator has reserve capacity for powering gyros and other special model circuitry requiring 400-cycle power. The battery-charging and power-control circuitry is arranged for simplified operation and the use of a minimum amount of equipment in the model.

The basic readout circuitry included with the system is only enough to guide the operator in controlling the model. Connections are provided for recording these data on external equipment. One spare proportional data channel has been included for use in certain tests in which it is desirable to initiate a new command when the model attains a specific rate of turn or heading angle. Connections have been included for adding up to twelve additional subcarrier data channels to the readout circuitry.

The 400-cycle power for the instrumentation in the model is rectified and regulated by semiconductor circuitry. Power supplies for all console equipment operate on the 60-cycle power lines and use vacuum tube regulators

2. RADIO-CONTROL AND TELEMETERING LINKS

Standard FM-PM telemetering equipment is used in the radio frequency and subcarrier portions of the radio-control and data-readout system. The block diagrams of the control equipment are shown in Figures 1 and 2. Figures 3 and 4 show the block diagrams of the readout circuitry.

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*The discriminators are called Demultiplexers by the manufactuer.

Proportional control or readout data are applied to potentiometer-controlled subcarrier oscillators. Variation of the potentiometer slider causes frequency modulation of the subcarrier oscillator. For model equipment simplicity and increased readout accuracy, reactance-controlled subcarrier oscillators are used in the rpm readout circuits (Figure 3). In this application, soft iron slugs are used to vary the inductance of a tank circuit which in turn controls the frequency of the subcarrier oscillator. Separate subcarrier oscillators and controls are used for each channel of information. Standard IRIG* subcarrier frequencies are used with band selection based on use of preferred bands and type of data to be transmitted. The frequency range of 200 to 500 cycles per second is used for the on-off control tones. This requires the elimination of IRIG subcarrier band No. 1 which has a center frequency of 400 cycles per second.

The control tones are generated by a group of resonant-reed oscillator-control units. The resonant reed has a very high Q and good frequency stability which permits the use of many channels within a small range of frequencies. Feedback power for driving the reed is provided by a single-stage vacuum-tube amplifier. Because of their high-Q and long buildup time, the oscillators are allowed to run continuously and their output is switched on or off as required.

The outputs of the resonant-reed circuits are mixed in a resistance network and then passed through a low-pass filter to remove harmonics. The filtered tones are then mixed with the outputs of the subcarrier oscillators. In the control link (Figure 1), the mixing is performed in an operational amplifier circuit which is capable of driving the transmitter circuitry via the interconnecting cable in the console. In the model readout link (Figure 3), the operational amplifier is replaced by a simple resistive mixing network which drives the transmitter through a very short cable.

The transmitters are crystal-controlled, phase-modulated units and have a maximum power output of 3.5 to 4.5 watts. Since full power is not required for this application, the transmitters are operated at reduced plate voltage to extend tube life. Power output under these conditions is about 2 watts.

Ground plane antennas are used for all transmitting and receiving circuits. These antennas are small, lightweight, and omnidirectional, and provide proper impedance match for the transmitters and receivers.

Miniature crystal-controlled FM receivers are used in both the control and readout circuits. The receivers contain a plug-in RF section for channel selection, but have no controls to be adjusted during operation. The output of the receivers is sufficient to drive all subcarrier and tone-channel circuitry. The receivers have an automatic gain-control circuit for operation over a wide range of signal levels. The AGC circuit output is also used for control of external circuitry.

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*Inter-Range Instrumentation Group.

The subcarrier channel signals are separated from the composite receiver output by the frequency-selective input circuitry of the discriminators. Following stages of the discriminators clip and demodulate the subcarrier signal and produce an output current or voltage proportional to the signal applied to the subcarrier oscillator in the transmitting end of the radio link. The discriminator is insensitive to variations in amplitude of the input signal, above threshold, and responds only to frequency variations. Two controls, for balance and output level, are provided in each discriminator in addition to a meter which indicates relative amplitude of the output signal.

The low-frequency tone signals are separated from the composite receiver output signal by a low-pass filter. The tone signals are then amplified and applied to a group of resonant-reed relays. These relays are highly frequency-selective and are tuned to frequencies matching the resonant-reed oscillator-control units in the transmitting end of the radio link. The contacts on the resonant-reed relays close for only 5 percent of each cycle of their resonant frequency and have limited current-carrying capabilities. These short contact closures are used to charge a capacitor in the grid circuit of a vacuum tube amplifier. The plate circuit of the amplifier contains a multi-contact relay which is capable of handling the currents required by other sections of the control or readout instrumentation.

3. CONTROL EQUIPMENT

3.1 RUDDER CHANNEL

The rudder control system is designed to operate one or two rudders from a common servo system. Three groups of rudder controls are included to handle various types of maneuvering tests. The PRESET or STEP methods of control should be used when it is desired that the rudder run into a new position at a constant velocity. The WHEEL control will be most useful for random maneuvers and for adjustment of average course when an external programming signal is used. The servo system is designed to be used with the radio-control link or in a cable-controlled system. It may be used as a simple proportional servo, with a no-load run-in rate of about 56 degrees per second which is desirable for external programming, or as a velocity-stabilized system with adjustable run-in rate. The servo unit contains adjustable limit cams which reduce servo torque at any desired shaft positions. Mechanical linkage is provided for coupling a second rudder shaft to the servo unit. An adapter plate and two bearing assemblies are included for using existing rudder-force dynamometers on one or two shafts.

All console rudder controls are mounted on the left panel of the console, Figure 5. Type of control is selected by the switch on the left side of the panel. The first type of control is PRESET. In this mode of operation the three controls at the top of the panel are used. The multiturn potentiometers are calibrated directly in degrees and may be set for any desired Port and Starboard rudder angles. The selector switch at the top center of the panel may

then be used to switch to either PRESET position or to a position of zero rudder angle. The second type of control is WHEEL which allows the operator to select any desired rudder position by means of a single knob at the lower, center portion of the control panel. The third type of operation is STEP control. When this control is used, the operator may position the rudder servo in 5-degree steps covering a total range of 90 degrees. Further versatility may be had by presetting groups of controls and then using the SELECTOR switch to change from one group of controls to another.

The control circuitry is arranged for programming the rudder from an external signal source, such as a Hewlett-Packard Low Frequency Generator Model 202A or equivalent. The only restrictions are that this input be isolated from ground, have a low impedance, and not have a large d-c component. Square, triangular, or sinusoidal rudder motions may be simply generated in this fashion. Servo followage will be limited by the frequency and amplitude of the applied signal and servo loading.

The output of these control circuits is used to drive the subcarrier and RF circuitry of the rudder control portions of the radio-control link. In the model, the output of the rudder-channel discriminator is applied to the servo amplifier input.

The rudder servo system is of special design to meet the requirements of model testing. It may be controlled by the radio link or cable control. When radio control is used, the external control voltage is compared to the output of the feed-back potentiometer R_1, Figure 6. When the cable-control circuit is used, the d-c reference within the servo system is applied to both the feedback and the external control potentiometers. For either method of control, the control and feedback signals are mixed in the first summing network A_1.

Switch S_2 changes the system from standard proportional control to velocity-stabilized proportional control. The switch is shown in the position for standard control. Any difference signal produced by the summing network is converted to an a-c signal at line frequency by the modulator stage before amplification. Several stages of vacuum tube amplification are used ahead of a commercial transistor preamplifier and magnetic output stage which drives the servo motor. The tachometer generator is direct-coupled to the motor and a portion of its output is applied to the second summing network A_2 and used for damping. The gearbox has a reduction of about 1000 to 1 which provides a no-load output speed of about 56 degrees per second as shown in Figure 7.

Velocity-stabilized operation requires the additional circuitry shown within the dashed line of Figure 6. Circuit changeover is performed by switch S_2. Part of the output of the first stage of amplification is applied to a phase-sensitive detector and polarized relay. Detector sensitivity is adjusted so that the relay contacts close as soon as there is a difference of 1 degree between the actual servo position and the commanded position. Transformer T_1 and Potentiometer R_1 furnish an adjustable 400-cycle reference voltage for the velocity-stabilizing circuit which is compared to the tachometer output when the relay contacts are closed. The proportional control signal applied to the summing network A_2 is reduced by the

ratio of Resistor R_2 to the output impedance of the $T_1 - R_1$ reference circuit. In this condition the tachometer output is compared to the preset reference voltage, and the motor drive is automatically adjusted to maintain the preselected velocity. Changes in servo loading affect the tachometer output, and appropriate compensation is performed by the feedback loop. When the servo is within 1 degree of the command position, the polarized relay returns to its central position. The velocity-reference signal is removed and the proportional control signal restored. A damping signal of appropriate amplitude is applied through R_3. With proper adjustment of the damping signal, the servo will run-in to a preselected position with negligible undershoot or overshoot. The speed-load curve for several velocity settings is shown in Figure 7. Velocity control setting versus speed is shown in Figure 8.

3.2 PROPULSION-CONTROL CHANNELS

The radio-control system contains two separate propulsion-control channels. Either channel may be used separately, or both may be used simultaneously. Propulsion power and direction of motor rotation are remotely controlled by levers on the console. Propulsion-motor voltage is approximately linearly proportional to lever position. Power for the propulsion motors is obtained from motor generators driven by a storage battery as described in the following section on Power and Power-Control Equipment. Motor-generator output voltage is controlled and regulated by an error regulator which amplifies a low-level error signal to a level capable of driving the field of the generator. The propulsion system is designed for use with series-wound d-c motors requiring 3 kilowatts or less. Propulsion motors are reversed by reversing connections to the motor armature. One or more propulsion motors may be used on each motor-generator as long as the maximum current output of 10 amperes is not exceeded.

Propulsion-motor speed and direction are remotely controlled by subcarrier and tone channels. The propulsion levers control tapped potentiometers and microswitches. The potentiometers control the frequency of subcarrier oscillators and are arranged so that the full dynamic range of the subcarrier circuit is used for either the forward or reverse condition. The microswitches control relays which turn tones on or off depending upon the direction of motor rotation desired. Four tone frequencies handle all possible conditions of propulsion-motor control in addition to the fail-safe circuitry described in the following section. When tone "A" is on, both propulsion motors are connected for forward operation. If tone "B" is on, only the port motor is reversed, or if tone "C" is on, only the starboard motor is reversed. Tone "D" reverses both motors. These propulsion-control signals are combined with the other control signals and transmitted over the common radio-control link. The propulsion discriminator(s) and tone detectors in the model separate the propulsion-channel data from the composite-control signal. The output of each discriminator is applied to an error regulator which controls and regulates motor-generator output voltage.

3.3 FAIL-SAFE CIRCUIT

The fail-safe circuit is included to insure against loss of control of the model power due to failure of control circuit equipment or signal dropout due to multipath reflections.

A switch on the propulsion-control panel marked POWER AND FAIL-SAFE may be used at any time to cut off all model power. This switch controls the power to relays which control the outputs of the tone oscillators used for controlling the direction of rotation of the propulsion motors. The tones are transmitted to the model via the common radio link.

Two sections of the model equipment contribute to the fail-safe circuitry. The automatic gain-control voltage of the receiver is used to hold a relay latch. Loss of RF signal due to either transmitter or receiver failure, or signal loss due to signal cancellation by multipath reflections causes a relay contact to short out the input to the tone detector circuitry. The tone detector circuitry is arranged so that any one of the four tones must be on to hold the fail-safe relay closed. This relay is then used in latching circuits for the motor-alternator and motor-generator units which are described in the following section of this report. All latching circuits are arranged so that once the command signal has been removed or lost, it is impossible to restart the equipment without the use of the alternator and generator starting unit.

3.4 SPARE TONE CHANNEL

A spare tone channel has been included in the control circuitry to provide remote operation of relay-controlled circuits. This can be used for operation of calibration circuitry or other special equipment. The capabilities of this channel can be easily expanded by incorporating a stepping type of switch in the model.

A switch and pilot light are mounted on the power control panel of the console. When the switch is turned on, a tone is transmitted over the radio link which operates a relay in the model equipment. The opening or closure of these relay contacts may be used to control any desired function.

4. POWER AND POWER-CONTROL EQUIPMENT

4.1 GENERAL

The selection of the equipment was made after considerable searching, comparing, and conferring. Some components are production items, others are modified stock items, and a few are special designs. The primary consideration in the acquisition of the model-borne equipment was minimum weight. The motor-generator sets, the alternator sets, and the 10-ampere-hour batteries were specially designed for the minimum-weight application.

4.2 BATTERIES

Three nickel-cadmium batteries are provided: two 10-ampere-hour batteries (one spare) for minimum-weight tests and one 40-ampere-hour battery for use when two motor-generator sets are required in the model. The batteries are of sintered-plate construction which permits the high-current rates required. Each battery has 34 cells and an open-circuit terminal voltage of 44.2 volts when fully charged. The internal voltage drop reduces the terminal voltage to 36 to 38 volts under load. Each battery is large enough so that no more than 50 percent of its capacity is consumed during a test run. However, as the batteries age, their capacity diminishes and replacement is necessary when one-half capacity is reached.

4.3 MOTOR-GENERATOR SETS

The motor-generator sets were specially designed to incorporate 3 kilowatts into as compact and as light a piece of equipment as possible within the limits of good design standards. The set is composed of a 36-volt, 150-ampere, 7600-rpm, d-c shunt motor driving an intermittently rated 3-kilowatt, 0–300-volt, separately excited d-c generator. The motor is capable of withstanding the 49 volts which is applied by the battery charger during charging operations. The generator output is continuously variable from zero to 300 volts and is controlled by the error regulator which supplies the generator field. The generator, which can deliver a current of 10 amperes, feeds through a reversing relay to a series motor for propulsion. The 3-kilowatt rating is based on the following duty cycle:

3	kw for 2 minutes;	no load,	10 minutes
2.4	kw for 2 minutes;	no load,	10 minutes
1.8	kw for 2 minutes;	no load,	10 minutes
1.2	kw for 2 minutes;	no load,	10 minutes
0.6	kw for 2 minutes;	no load,	10 minutes

Other duty cycles may be used provided the motor-generators are not allowed to overheat.

A resistance temperature detector (RTD) unit is imbedded in the motor field and connected to a bridge circuit. A small meter shows the field temperature in degrees Centigrade divided by 100.

If the meter approaches full scale, the motor-generator set should be allowed to cool off before proceeding with model tests. The maximum cooling rate will be obtained by allowing the motor-generator to run without load.

4.4 ERROR REGULATOR

The error regulator is a feedback device which regulates motor-generator output by control of field current. As shown in the block diagram (Figure 9), the control signal and a portion of the generator output are compared in the magnetic modulator which has two isolated inputs. A regulated d-c internal reference is resistively mixed with the generator output. The signals applied to the modulator are mixed in the magnetic circuit and produce an output at

powerline frequency which is proportional to the difference between the command signal and the generator output. The resulting error signal is rectified in a phase-sensitive demodulator and then passed through a d-c amplifier. Power level is increased to a maximum of 30 watts which is sufficient to drive the generator to full output. Transient response of the regulator is improved by the lead network in the feedback loop which provides a damping factor of about 0.6. Full-scale output voltage may be set for either 150 or 300 volts by the range switch which controls feedback signal and amplifier gain. Amplifier gain is sufficient to hold the generator output to within ± 1 percent of the command setting for changes in load or battery voltage.

4.5 MOTOR ALTERNATOR

Power for the error regulator and all electronic instruments is supplied by the motor-alternator set. This specially-designed set consists of a 36 volt, 12,000-rpm, d-c shunt motor driving a 115-volt, 400-cps, 3-phase, 750-watt alternator. A governor on the motor maintains the speed constant within 2 percent. The duty cycle of the alternator set is continuous. The motor can withstand the 49 volts which is applied by the battery charger during charging operations between runs.

4.6 BATTERY CHARGER

The battery charger requires a 3-phase, 600-volt source capable of delivering 20 amperes of current and it can deliver up to 300 amperes at 49 volts d. c. The charger is capable of quick-charging the 40-ampere-hour battery at a 200-ampere rate while simultaneously supplying power to a motor-alternator set and two motor-generator sets. The charger is fan-cooled and consists of three single-phase, tapped-primary transformers feeding a 3-phase bridge selenium rectifier. The charger features a timing relay adjustable from zero to 8 hours which automatically turns the charger off at the end of a preset charging period. The timing cycle starts when the charging rate switches from the high rate to the low rate. A 10-kva, 3-phase, 480/600-volt autotransformer is provided to enable operation of the 600-volt charger from a 480-volt supply.

4.7 STARTING EQUIPMENT

Reduced-voltage starting of the motor-alternator and motor-generator sets is accomplished by inserting additional resistance in the armature circuit of the motors. These resistors are automatically cut out of the circuit by time-delay relays which short them out at preset time intervals. The running contactor in the model is the final shorting step and when it pulls in and seals, the starting cable may be disconnected from the model after the STOP button is pushed. The START-STOP pushbutton station, the resistors, and the time-delay relays are mounted on the battery charger.

5. READOUT EQUIPMENT

A limited amount of data readout equipment has been included in the radio-control system. This is to guide the console operator in maneuvering the model and to supply a continuous check on proper behavior of the control circuitry. The system is designed so that the telemetering link may be expanded in the event that additional analog data channels are required.

The system includes circuitry for console indication and external recording of rudder position, two channels of propulsion shaft rpm, and one spare data channel. The running time of the rudder servo is indicated on a clock on the console. One spare ON-OFF tone channel is also included for operation of auxiliary equipment. All readout circuitry is arranged so that the data may be recorded on equipment currently in use at the Model Basin.

5.1 RUDDER CHANNEL

5.1.1 Rudder Position

The rudder servo unit contains a 5000-ohm center-tapped potentiometer which is coupled directly to the output shaft of the servo. The readout circuitry is arranged so that either analog or digital data transmission may be used.

5.1.1.1 Analog Readout. The analog method, for which all equipment is furnished, is a simple subcarrier circuit. The potentiometer is used to control the frequency of a subcarrier oscillator. This signal is mixed with other subcarrier signals and is transmitted over a common radio-frequency link. The signal is received at the console and separated from the other subcarrier signals by the rudder channel discriminator. The output of the discriminator is connected to the RUDDER ANGLE meter on the console panel and to a connector for operation of an external recorder requiring $\pm$ 1.0 milliampere or less.

5.1.1.2 Digital Readout. The second method of rudder position readout is for use when greater accuracy and elimination of telemetering system drift is mandatory. In this system, rudder position data is converted to digital form in the model, thereby eliminating the effects of drift and nonlinearity in the telemetering link. All equipment is furnished for this system except the analog-to-digital converter. In the system recommended in the original specification,[2] a velocity-controlled servo would generate a train of rectangular waves with the rate proportional to the displacement of the rudder shaft potentiometer from the 0-degree position. The output frequency would be 5 cycles per second per degree of rudder offset. An alternate system would be to use a very accurate voltage-to-frequency converter similar to the Dymec Inc. Model DY-2210 with the output rate reduced to the aforementioned value. The output of either of these systems would be used to modulate a voltage-controlled subcarrier oscillator. A microswitch mounted on the rudder servo unit turns a tone channel ON or OFF

depending upon the direction of rudder shaft displacement from zero. Both signals would be mixed with other readout data and transmitted over the common radio link.

The console contains all circuitry for using this type of rudder position readout. The output of the rudder channel discriminator is used to drive a squaring and frequency-doubling circuit. The output of this circuit may be used to drive an external digital indicator and recording system with rudder position displayed to the nearest tenth of a degree. The tone circuitry would be used to operate a port-starboard indicator or marker. Standard digital events-per-unit-time meters and recorders may be operated from this circuitry.

For console indication the output of the squaring and frequency-doubler circuit is used to drive a pulse-rate-to-current converter. The output of the converter is applied to the RUDDER ANGLE indicator. Meter polarity is automatically reversed by the tone circuitry as the rudder is moved from port to starboard positions.

5.1.2 Rudder Running Time

The rudder running-time circuit control signal is obtained from the output of the tachometer generator in the servo system. The output of the tachometer is applied to an amplifier which drives a sensitive relay. A gain control in the amplifier is used to select the velocity at which relay operation takes place. One set of relay contacts is brought out to a connector on the model-borne readout unit for control of lamps used when the model ships are tracked photographically. Another set of contacts is used to turn a tone ON which is transmitted to shore over the common radio link.

In the console, a tone detector circuit separates the running-time signal from the other tones and operates a relay which controls current to the clutch of an electric clock mounted on the rudder control panel.

The overall accuracy of this system is somewhat limited because of the number of electromechanical delays. Accuracy is also affected by the run-in rate of the servo and the setting of the amplifier gain control. However, under most conditions, rudder running time will be indicated to within 0.1 second or better.

5.2 RPM CIRCUITS

The two channels of propulsion shaft rpm circuitry are of nonstandard design in order to achieve a higher degree of accuracy and stability than is possible by the standard FM-PM telemetering technique. Both channels are identical except for choice of subcarrier frequency.

The rpm pickup consists of a small aluminum wheel with five soft iron inserts and an E-core pickup mounted in a yoke attached to the shaft of the wheel by ball bearings. The shaft is hollow and designed to clamp onto an intermediate 5/16-inch-diameter propulsion shaft. The yoke is fastened to the model hull by a thin strap and holds the E-core coil at a fixed distance from the surface of the wheel.

The coil of the E-core assembly is connected to a reactance-controlled subcarrier oscillator. The coil and capacitors within the oscillator unit form the tank circuit of an oscillator. As the wheel is rotated, the inductance is varied, causing a change in subcarrier frequency. The subcarrier output is then mixed with the other subcarrier signals and transmitted to the console where it is separated from other readout data by the discriminator.

The discriminator output is a variable low-frequency voltage whose frequency is proportional to shaft rpm. The signal frequency is doubled and then shaped into a rectangular wave. The output of the shaping circuit may then be used to drive an external indicating-recording system such as the TMB Revolutions-Speed-Time Recorder Type 223 or a standard events-per-unit-time indicator and recorder.

The output of the pulse shaper is also used to drive a pulse-rate-to-current converter stage where current output is proportional to pulse-input rate to an accuracy of better than 1 percent. This current is used to drive the rpm meter on the console. Full-scale ranges 0–1500 or 0–3000 rpm for both channels may be selected by a switch on the propulsion control panel.

5.3 SPARE ANALOG CIRCUIT

A spare analog circuit is included in the telemetering link. The spare receptacle in the readout unit is wired for an Electro-Mechanical Research Model 94 potentiometer-controlled subcarrier oscillator. The console end of the link is wired for a spare Tele-Dynamics, Inc. Type 2201C Demultiplexer.* The output is connected to the 1-0-1 milliampere meter on the console marked SPARE, and also to an output connector which can supply $\pm$ 1.0 milliampere to an external load.

5.4 SPARE TONE CIRCUIT

Connections are included in the readout unit for a spare tone channel. The circuit is operated in the model by the closing of external contacts which turn on the tone. It is relayed to shore via the telemetering link and is there used to operate a set of single-pole double-throw relay contacts which are available at a connector on the console. System response time is limited to about 0.1 second by the operating time of the relays and tone detector circuitry.

6. POWER SUPPLIES

6.1 CONSOLE EQUIPMENT

The power supplies for all console equipment are mounted in two chassis at the rear of the console. Power supplies for all control circuitry are constructed in the smaller chassis

*Trade name for discriminator.

and for all readout circuitry in the larger chassis. All power switches and line fuses are mounted on the power control panel. Plate power for all equipment is regulated by vacuum tube circuitry. Regulators are of standard TMB design with regulation for changes in line voltage or load. A switch panel and test set, located under the power control panel, provide a quick check on all console power supplies.

6.2 MODEL EQUIPMENT

All primary instrumentation power is supplied by the 400-cycle motor-alternator. The a-c power is applied to the individual units of the model equipment which have self-contained or separate power supplies. All major power supplies are commercial transistor-regulated units. The transistor-regulated supplies contain quick-blow internal-circuit fuses in addition to the panel fuses which are in the main line. Panel test points are provided for all regulated supplies to facilitate rapid location of defective units. The servo amplifier and error regulators have self-contained power supplies with silicon rectifiers and zener diode regulation.

7. CONCLUSIONS

The complete system has been tested in the laboratory and in several model ships. Individual sections of the system have undergone extensive laboratory tests and calibrations. The telemetering equipment has performed according to the manufacturer's specifications as to linearity and stability. The special equipment such as the rudder servo, the powering equipment, and the special readout circuitry have performed as originally specified. The speed-load curves for the rudder servo in both modes of operation are shown in Figure 7. The servo was also checked with a programmed input, and servo followage was good up to the load-velocity limitations of the system.

The propulsion powering system was checked with resistive loads and with motor loads in free-running and moored models. The motors used were 220-volt, 1/2-hp units, and were operated in normal and overload conditions. Complete tests with motors at full power were impossible since 3-hp motors and suitable dynamometers were not available. Motor drive voltage and model speed were checked during several straight runs at moderate speed on a single charge of the battery. Motor voltage held to better than 1 percent of the command value until the test was terminated when the battery charge was down to 0.8 volts per cell. Change in model speed was negligible and could probably be attributed to the effects of motor heating which are not compensated for in the feedback loop of the powering system.

The performance of the radio frequency equipment at an RF output of about 2 watts was satisfactory for all model tests. The model was operated in the J-shaped turning basin with the control console located either on the towing carriage or at various points around the basin. The antennas were strapped to the carriage members or fastened to wooden pedestals when used on shore; they were placed at least 10 feet apart but no other precautions as to location

were taken. The model was operated at distances of from 10 feet to over 650 feet away from the console equipment. Control and readout communications were maintained throughout the range except in several instances when several observers intercepted the line-of-sight RF path. In these instances, the power to all model equipment was turned off by the fail-safe circuitry. There was no noticeable loss of signal due to multipath reflections.

8. RECOMMENDATIONS

The design of the system is based on the use of modular components for both the console and the model equipment. Many portions of the system use vacuum-tube circuitry because transistorized equipment of equivalent electrical characteristics was not available when the design was in progress and material was being ordered. It will be possible to replace these components with similar transistorized items of superior characteristics as new equipment becomes available.

Transistorized subcarrier oscillators with better linearity than those used in the system are just becoming available. Transistorized subcarrier discriminators with specifications similar to those used in the present system are also available. Substitution of these components in the model equipment would result in a small reduction of weight and power consumption. It is possible that in a few years even greater improvements will be made in this type of equipment.

If smaller receivers and subcarrier discriminators become available it should be possible to use the present console equipment to operate a completely new set of model equipment which would be suitable for use in 10- to 15-foot models. Since the propulsion requirements would be considerably less for this application, a much lighter battery and simpler propulsion motor and rudder control circuitry could be used.

Solid state inverters are now available which meet or exceed the electrical specifications of the motor-alternator used in the system with the exception of range of input voltage. It is believed that this could be taken care of with slight modification.

Solid state power converters are presently being manufactured at ratings up to 5 kilowatts and it may be possible in the near future to replace the motor-generators and error regulators of the present system with units of greater efficiency and lower weight. Other advantages gained by the replacement of the rotary equipment would be the elimination of gyroscopic effects and noise. Some reduction in maintenance might be achieved.

Some modifications and additions which could be made to the existing equipment would result in improved performance. It now seems highly desirable to add an adjustable current-limiting circuit to the error regulators for the motor-generators. This would eliminate the need for fuses in the output of the motor-generator and also prevent the application of large momentary overloads to the propulsion motors.

It may also be highly desirable to provide some method for obtaining a good impedance match between the motor-generators and the model propellers. This could be accomplished

by using a greater assortment of motors and propellers or by the use of an intermediate speed changer. Final determination should be based on both a hydrodynamic and an electrical evaluation of requirements.

9. ACKNOWLEDGMENTS

The radio-control system was designed by members of the engineering divisions of the Industrial Department. The final system requirements were the result of conferences between Mr. W.F. Brownell, Mr. S.C. Gover, and Mr. F.D. Bradley of the Hydromechanics Laboratory; Mr. H.E. Prucha and Mr. P.M. Douglass, Jr. of the Facilities Division; and Mr. W.S. Campbell and the author of the Instrumentation Division.

The control-system design was done by the author with many valuable suggestions contributed by Mr. Campbell, both of the Instrumentation Division. Design of the powering and propulsion equipment was handled by Mr. Douglass and Mr. R.C. Goodson of the Facilities Division. Mr. Stern of the Instrumentation Division designed the mechanical portions of the rudder servo system.

Mr. Goodson also participated in the final system checkout and prepared the sections of this report which concern the powering and propulsion equipment.

PART III – INSTALLATION AND OPERATION

1. INSTALLATION

1.1 SHORE EQUIPMENT

The "Shore Equipment" has been designed for use either on the towing carriage or for a fixed installation in one of the testing areas of the Model Basin. All shore equipment may be located in a group or, if desired, the battery charger may be located at a convenient point near the water, and all other equipment at a position allowing an unobstructed view of the maneuvering area.

1.1.1 Console and Antennas

The console should be positioned so that the operator will be able to view the model maneuvers over the top of the console. This will permit the operator to watch the model and the console indicators much as the dash panel instruments of an automobile are observed while driving.

The transmitting and receiving antennas should be vertically mounted with a spacing of 10 feet or more between antennas and positioned so that metal objects or personnel will not intercept the path between the shore-based antennas and those on the model. The cables between the console and the antennas should be of Type RG-58/U in order to maintain proper impedance matching. The length of these cables is not critical; however, it is desirable that their length not exceed 25 feet because of the high cable losses at the operating frequency. NOTE: Transmitter power should never be turned on unless the transmitting antenna is connected.

Two power input connectors are mounted in the base of the main pedestal of the console. The 60-cycle power for all electronic circuitry should be regulated to 115 volts $\pm$ 5 volts and connected to the left input connector; see Figure 10. Maximum regulated power required is 600 watts. The other power input connector should be connected to an unregulated 115-volt 60-cycle power line that is always turned ON. This supplies power to the console cooling, heating, and illumination circuitry. The heaters are turned ON whenever the OPERATE STANDBY switch is in the standby position. This is to prevent the accumulation of moisture within the console when used in areas of high relative humidity. Unregulated power is available at the fused outlet on the front of the console and may be used for the operation of test equipment or a soldering iron. The maximum unregulated power requirement for the console equipment is 100 watts.

1.1.2 Battery Charger

The battery charger should be located at a position allowing convenient access to the battery and the motor-generator and motor-alternator connectors of the model equipment. The charging and starting cables are approximately 20 feet long. The charger is designed for use on a 3-phase 600-volt power line. The maximum power requirement is approximately 20 kilowatts. An auxiliary transformer is provided for operating the charger from 480 volt lines. The starting circuitry for the motor-alternator and motor-generator requires 115 volts at approximately 100 watts.

1.2 MODEL EQUIPMENT

The model equipment is composed of a group of small units which may be distributed about the model to obtain approximate model trim. Cable lengths have been arranged to permit considerable shifting of units when arranged in the following manner: The receiving antenna and receiver should be placed near the bow. These should be followed by the receiver and demodulator power unit and then the demodulator rack. The battery, the motor-alternator, and one or two motor-generators should be centrally located to permit the use of short leads in the high-current circuitry. The error regulator (s) may be mounted anywhere within cable range of the motor-generator (s). Location of the propulsion motor (s) will normally be determined by the position of the propulsion shaft (s). The RPM pickup (s) should be mounted on the intermediate propulsion shaft near the readout unit. The readout unit should normally be near the rear center of the model and may be placed above or between the propulsion shafts. The servo amplifier should be placed near the rear of the model and the servo unit placed directly over the rudder shaft. The transmitting antenna should be located as close to the stern of the model as possible and slightly higher than the rudder servo.

All chassis should be securely fastened to the model and placed at least 1 inch above the bottom to prevent water damage. If the model is to be used in rough water tests, splash protection is required.

Shock mounts are provided for the motor-alternator and motor-generator units and should always be used to prevent transmission of vibration to the model and the electronic circuitry.

The rudder servo may be used with or without the dynamometer attachments and may be used to control one or two rudders. When two rudders are used, the servo unit should be connected to the port rudder with the starboard rudder connected to the servo by the parallelogram-type linkage. NOTE: The zero rudder position should be set by shifting rudder shaft position or servo unit mounting position, but not by adjustment of shafts or gears within the servo unit.

The weights of the model equipment units are shown in Table 2. The demodulator rack has spaces for two propulsion channel discriminators. When only one motor-generator is used, the discriminator for the unused channel may be removed and a blank panel substituted. The protective covers for several of the chassis may be removed where weight limits are extremely critical. The weights of typical systems, including cables, are listed in Table 1.

The model equipment should be connected as shown in Figure 11. The numbers shown in circles represent cable numbers. The length and weight of the cables are shown in Table 3. All multiconductor cable connectors are polarized to prevent improper interunit connections.

The motor-generator (s) should be fused according to the ratings of the propulsion motors to be used. Fuses should be of the slow blow type with the rating not exceeding 10 amperes. See Figure 49 for location.

Connections to the output of the motor-alternator are not shown in Figure 11 because the alternator has a 3-phase output and the load must be equally distributed between phases. The output connectors are arranged in three longitudinal rows of three connectors each, with one row per phase. The three end connectors are for 3-phase loads or special single-phase loads, such as the rudder servo, where it is desired that the load operate on a phase having a particular lead at ground potential. Power input requirements for the model equipment are listed in Table 2. Additional equipment, such as gyros or tracking lights, should be considered when distributing the load. A reference chart for typical installation is posted in the console.

1.3 AUXILIARY EQUIPMENT

The radio control and readout system contains circuitry which may be used in conjunction with other instrumentation now in use at the Model Basin. This section of the report is intended to serve as a guide to the proper installation and use of such equipment.

1.3.1 Control Equipment

1.3.1.1 Rudder Programming. The connector on the console marked program input permits a low-frequency function generator, such as the Hewlett-Packard Model 202A, to be used to apply repetitive signals to the rudder servo. This input may be of any wave shape; however, servo followage will depend on the frequency, wave shape, and amplitude of the applied signal.

The signal should be applied to the AN-3102-14S-7S connector. Pin A is the chassis ground connection, and pins B and C are for the signal input circuit which is about 150 volts above ground.

Any of the rudder-control methods may be used for setting initial rudder position after the function generator has been adjusted for zero direct-current output. Frequency, amplitude, and type of rudder motion may be adjusted by the controls on the function generator.

1.3.1.2 Spare Tone Circuit. This tone circuit is controlled by the SPARE TONE switch on the power control panel of the console. This actuates a relay in the tone detector unit. Single-pole double-throw contact terminals are available at the SPARE TONE connector Type AN 3102-10S-3P on the demodulator rack. Pin B is connected to the arm of the relay and pins A and C are connected to the normally open and closed contacts.

1.3.1.3 Modulation Output. The modulating signal, applied to the control circuit transmitter, is available at a UG-291B/U connector in the console. This may be used for recording the modulation signal applied to the transmitter.

1.3.2 Readout Equipment

1.3.2.1 Rudder Channel. An analog current or voltage, proportional to rudder position, is available for external recording at the console connector marked Analog Rudder. Terminal A of the AN 3102-14S-1S connector is chassis ground, and terminals B and C are the differential signal output which is about 45 volts positive with respect to ground. This output is in parallel with the meter on the console so any external load should be of constant impedance and draw 1 milliampere or less. Maximum output voltage is about $\pm$ 3 volts. The console meter may be recalibrated by use of the centering and sensitivity controls on the discriminator, but separate calibration circuitry must be used for the external equipment.

If an analog-to-digital converter is used in the model as described in Section II, 5.1.1.2, a digital output may be obtained from the Cannon Type XL-3-14 connector marked Rudder Angle. Pin 1 is ground, pin 2 is the pulse output, and pins 1 and 3 are connected to a relay which may be used to control a port-starboard marker. The pulse output may be connected to any standard events-per-unit-time meter. Peak pulse amplitude is approximately 25 volts into a 600-ohm load. Pulse output rate is 10 pulses-per-second-per-degree of rudder offset.

1.3.2.2 Propulsion Shaft Rpm. A pair of Cannon XL-3-14 connectors are provided for accurately indicating or recording propulsion shaft rpm on digital equipment. Pin 1 is ground, and pin 2 is the pulse output. Pulse amplitude is about 25 volts peak into a 600-ohm load, and repetition frequency is 10 pulses per revolution. The output of these circuits may be used to drive the TMB Revolution-Speed-Time Recorder Type 223, which automatically prints out rpm on a Clary Printer. Standard commercial events-per-unit-time meters and printers may also be used.

1.3.2.3 Spare Analog Channel. The connections to and use of the spare analog channel are the same as for the analog rudder circuit. Output is obtained from the connector marked Spare Channel.

1.3.2.4 Receiver Output. The receiver output, of the model-to-console data link, is available at a UG-291B/U connector on the console. This may be used for recording the composite readout data on tape. It may also be used for driving additional discriminators if more readout channels are added to the readout system.

1.3.2.5 Spare Tone Circuit. A spare tone circuit is included in the model-to-shore data link. The tone circuit may be energized by connecting switch contacts to terminals A

and B of the AN 3102-12S-3S connector on the readout unit marked Spare Tone. The output of the circuit is available at terminals of the AN 3102-14S-5P connector marked Spare Tone Contacts on the console. Pin A is connected to the arm of the single-pole double-throw relay and pins B and C to the other contacts. The contact rating is 1 ampere at 24 volts d. c. or 115 volts a. c.

1.3.2.6 Modulation Input. The readout unit of the model equipment has a modulation input connector which may be used for mixing the outputs of additional subcarrier channels with those in the existing readout system. A readjustment of the modulation schedule will be required to prevent overmodulation of the transmitter.

1.3.2.7 Tracking Lamp Control. The rudder running-time circuitry of the readout unit contains a relay which is energized only when the rudder servo is running. A spare set of single-pole double-throw contacts is connected to the tracking lamp connector on the unit. Pin B is connected to the arm of the relay and pins A and C to the other contacts. The contact rating is 1 ampere at 24 volts d. c. or 115 volts a. c.

1.3.3 Intercommunications System

The meter panel of the console contains a permanent magnet speaker which may be used as a speaker or microphone in a conventional push-to-talk multistation system. Changeover from listen to talk is controlled by a treadle-type switch on the console footrest. Connections are made via an AN 3102-14S-6P connector on the treadle switch. Pins A and B connect to the "talk" circuit and pins C and D to the "listen" circuit.

2. OPERATION

2.1 STARTING PROCEDURE

Shore – 1. Check all power, antenna, and readout cable connections.

2. Place all POWER switches on the console in the OFF position.
3. Switches for the panel meters are located on the rear of the control and readout unit. Place switches for unused channels in the OFF position. See Figure 18. An ON-OFF switch for the rudder running time indicator is located on the deck of the control and readout unit. See Figure 19. Place in the OFF position if running time circuit is not to be used.
4. Place OPERATE-STANDBY switch in the OPERATE position.
5. Check voltage of regulated line on panel voltmeter. Voltage should not exceed 120 volts.
6. Turn READOUT and OSC POWER switches ON.

Model – 1. Place switch on the alternator in the OFF position.

2. Place all other power switches on model equipment in the ON position.

3. Check all cable connections and connect alternator and motor-generator set(s) to battery. Observe polarity.
4. Set switch on error regulator(s) to desired output voltage range.
5. Set the CIRCUIT SELECTOR switch on servo amplifier to desired mode of operation. If automatic velocity control is used, set VELOCITY CONTROL for desired rudder rate according to graph, Figure 8.
6. Connect battery charger cable to battery. *DO NOT* turn charger ON. CAUTION: Do not operate charger with lower front panel removed.
7. Connect starting cable to alternator.

Shore – 1. Turn TRANSMITTER and POWER and FAIL-SAFE switches ON.

2. Press START button on top of battery charger.

Model – 1. Wait five seconds for alternator speed to stabilize. Turn ALTERNATOR POWER switch ON.

2. Wait 30 seconds for warmup of control equipment. At the end of this warmup, the meters on the discriminators in the demodulator rack should be stabilized. Depress the FAIL-SAFE HOLD switch on the top of the demodulator rack.

Shore and Model – 1. Press the STOP button on top of the battery charger and then disconnect the starting cable.

2. Check operation of the rudder control circuit by operating console controls. Meter deflection on rudder discriminator should be proportional to setting of rudder control. Rudder servo should follow setting of console control within $\pm$ 2 degrees.
3. Check operation of propulsion control circuit(s) by operating lever(s) on console and observing meter deflection on appropriate discriminator unit. When the control lever is at the OFF position, the meter pointer should be deflected to the right end of the scale. Moving the lever to either the forward or reverse position should cause the meter pointer to move toward the left end of the scale.
4. Place the propulsion levers at the OFF position.
5. Connect the starting cable to one of the MG sets. Press the START button on top of the battery charger and wait 5 seconds for the MG set to reach operating speed. Press the STOP button and then remove the starting cable.
6. When two MG sets are used, repeat the preceding step for starting the second unit.

Shore – 1. Set control knobs on battery charger to positions indicated on charging chart mounted on battery charger according to size of battery in use and number of MG sets in use.

2. Turn timer knob to 1-hour position. Cell voltage will normally be between 0.8 volts and 1.3 volts, depending upon state of charge of battery and will level off at about 1.3 volts as the battery approaches full charge. If charger will not come on,

because of low battery voltage, momentarily depress switch under ledge and just above the control panel.

3. Wait 15 to 30 minutes for stabilization of the electronic equipment.
4. Check calibration of system.

2.2 CALIBRATING PROCEDURE

This calibration check should be made after the equipment has been turned on for at least 15 minutes and about every 2 to 4 hours during the test.

2.2.1 Rudder Control Channel

a. Set RUDDER CONTROL SELECTOR switch to mode of operation to be used for majority of tests.

b. Place the rudder control knob at the ZERO rudder angle position. Check rudder shaft position by viewing the digital indicator on the servo unit. If rudder is not at zero, adjust CF BAL control of rudder discriminator in model.

c. Set control knob to 45-degree PORT and STBD positions. Check servo tracking at these points. If these points are off more than 0.5 degree, adjust the SENS control on the rudder discriminator. There is some interaction between the SENS and CF BAL controls, so a readjustment of both may be required. NOTE: Due to slight nonlinearities in various control circuit elements, it is almost impossible to obtain exact tracking over the whole range of rudder positions.

2.2.2 Rudder Readout Channel

a. Set rudder servo to zero on the digital position indicator. The rudder position indicator on the console should be at 0-degree. If not, adjust CF BAL control on the rudder discriminator in the console.

b. Set rudder servo unit to 45-degree PORT and STBD positions and check meter indication. If scale spread is not correct, adjust SENS control on the discriminator.

c. Repeat preceding steps if necessary.

2.2.3 Propulsion Control Channels

The propulsion channel circuitry normally will not require adjustment. The direction of motor rotation should be checked and if desired, motor speed may be checked against control lever position. When two separate propulsion channels are used, it may be desirable to adjust the discriminator SENS and CF BAL controls so that control lever settings are similar in the desired operating range.

2.2.4 RPM Readout Channels

a. Open control and readout unit drawer of the console.

b. Set rpm meter ON-OFF switches on rear of chassis according to channel (s) to be used, if not previously set.

c. Put the RPM TEST-OPERATE switch, located near the rear center of the chassis, in the TEST position. The panel meter (s) should indicate 720 rpm for either the 1500- or 3000-rpm scales. NOTE: The readout circuit telemetering link must be in operation for this check.

d. If meter calibration is incorrect, adjust appropriate trimmer capacitor on right side of control and readout unit chassis.

e. Place switch in OPERATE position and close drawer.

f. Slowly apply propulsion power and check rpm readout meter (s).

2.2.5 Spare Data Channel

When the spare Channel discriminator is used, the controls on the front of the discriminator should be adjusted as required for zero and full scale.

2.3 MODEL TESTING

Operating procedure during the model tests will depend upon the type of tests to be conducted so no specific procedure will be outlined. The rudder controls may be changed from one mode of operation to another at any time. The propulsion levers should not be moved rapidly except in an emergency. The field temperature of the motor-generators should be checked frequently when using high propulsion power.

2.4 EMERGENCY STOPS AND MODEL SHUT-DOWN

All model equipment may be turned off at any time by operation of the POWER AND FAIL-SAFE switch. If there is a loss of communication to the model, all power will be shut off automatically. The positive lead of the motor-generators and motor-alternators should be disconnected when the equipment is not being used.

PART IV – MAINTENANCE

1. DISCUSSION

The Type 304 Radio-Control System is composed of a group of commercially and specially designed units. The standard commercial items used in the system are (1) subcarrier oscillators, (2) telemetering transmitters, (3) telemetering receivers, (4) subcarrier discriminators (demultiplexers), and (5) transistor regulated power supplies. The motor-alternator, motor-generators, nickel-cadmium batteries and the battery charger are commercial units manufactured or packaged according to Model Basin specifications. All other units are of special design to meet system requirements. The maintenance of the transmitter, receiver, and subcarrier discriminators is fully described in manuals supplied by the manufacturers.[4,5,6]

All circuitry used in special units of the system is of straightforward design but many of the adjustments in these circuits are critical if optimum system performance is to be maintained. The control and readout sections of the system may be treated as separate systems except for common chassis ground and power input connections. In most cases it will be possible to isolate trouble to a specific channel or unit by means of the blown fuse indicators, the power supply test meter in the console, the power supply test points in the model equipment, or the meters on the discriminators in the model or shore equipment. Adjustments should not be made to the internal controls unless proper test equipment is available for checking the effect on the system. It should be noted that it will be necessary to completely check the calibration of units such as the subcarrier oscillators and discriminators if tubes are changed. It is suggested that personnel performing maintenance on the telemetering circuitry use "The Theory and Application of FM-FM Telemetry"[3] as a guide to circuit setup and testing.

The following sections of this part of the report describe precautions to be taken when replacing components and the procedures to be followed in making adjustments.

2. TELEMETERING EQUIPMENT

The general alignment and maintenance procedures for the transmitters, receivers, and discriminators are described in instruction manuals supplied by the manufacturer.[4,5,6] The adjustments described in the following paragraphs are those which are not described in the manufacturers' literature, or are unique to this system.

2.1 SUBCARRIER OSCILLATORS

2.1.1 Potentiometer Controlled

Each potentiometer controlled subcarrier oscillator has individual adjustments for setting the high and low band limits and the output level. A test point is provided for checking oscillator frequency. The control circuit subcarrier oscillators are shown in Figure 19 and the readout circuit oscillators in Figure 52. A list of subcarrier frequencies versus control or readout potentiometer settings is mounted in the console. When setting the subcarrier oscillators a digital frequency meter should be used for checking frequency; this frequency meter may be connected directly to the test point of the oscillator. After allowing at least 30 minutes for warmup, adjust the HIGH and LOW controls to obtain the frequencies listed on the chart. Repeat the adjustments if necessary as there is some interaction between controls. The procedure for setting the output controls is described in Section IV, 2.3.

2.1.2 Reactance Controlled

Reactance controlled subcarrier oscillators are used only in the rpm pickup circuitry. The frequency of the oscillators is adjusted by positioning the E-core pickup coil relative to the segmented wheel and by soldering silvered mica capacitors across the tank circuit within the oscillator. The poles of the E-core should always be parallel to the axis of the propeller shaft, and the distance between the core and the wheel varied by adjustment of the two lock-nuts. A preliminary check on the frequency deviation of the oscillators may be made by slowly rotating the pickup wheel and observing the deflection of the indicator on the discriminator. For a complete check, the output of an accurately calibrated discriminator should be connected to an oscilloscope. The pickup wheel should be rotated at speeds of from zero to 3000 rpm and the pickup and tank circuit capacity adjusted so that maximum frequency deviation is obtained without exceeding the band limits. It should be noted that the capacity of the cable from the pickup to the oscillator forms part of the tank circuit and any changes in cable length must be compensated by retuning the circuit. The output control on the oscillator should be adjusted as described in Section IV, 2.3.

2.2 TONE CIRCUITRY

2.2.1 Tone Oscillators

There are no adjustments to the tone oscillators except the output amplitude controls. The adjustment of these controls is described in Section IV, 2.3.

2.2.2 Tone Detectors

The tone detector circuitry consists of a common audio amplifier which drives a group of resonant reed relays. A gain control in the amplifier (R1 in the tone detector unit,

or R7 in the readout unit, Figure 19) is adjusted to provide a suitable level of driving current for the tone detectors. This current may be measured by reading the voltage drop at the test points which are across a 1-ohm resistor in series with the tone relays. Since the value of the driving current is subject to change if the system is expanded, the correct levels will be posted in the console.

2.2.3 Test Unit

A small tone detector test unit (Figure 35) has been constructed for testing the control circuits tone equipment. The unit is designed to plug into the motor-generator, motor-alternator, and spare tone outlets on the demodulator unit. The indicating lamps are arranged to show when the relays are closed.

In case of trouble with the tone circuitry, the tone relays should be checked first since they contain a vibrating contact which is subject to wear. In most cases it will be desirable to replace defective relays instead of attempting repair.

2.3 MIXING NETWORKS

The tone and subcarrier oscillator mixing networks in the control section of the console equipment and in the readout section of the model equipment are arranged so that each of the oscillators may be adjusted to supply the proper amount of signal to the PM transmitters. In addition to these, master amplitude controls for the transmitters are included. The levels for the individual signals are determined by setting up a modulation schedule based on the modulation sensitivity and the maximum allowable frequency deviation of the transmitter. Since the procedure for setting up this schedule is described in Reference 3, no attempt will be made to cover the subject in this report. It should be noted however, that only one of four tones in the propulsion-control system is on at a time. Each tone oscillator is set for the same amplitude and the modulation schedule is set up as though only one tone is being used. Since additional channels may be added to the system, a current modulation schedule for the control and readout links will be posted in the console.

2.4 TRANSMITTERS

The alignment and maintenance of the transmitters is fully described in the manufacturer's literature.[4] It should be noted that the transmitters are operated on a 200-volt supply instead of the 250-volt maximum. This reduces power output to about 2 watts.

2.5 RECEIVERS

The alignment and maintenance of the receivers is fully described in the manufacturer's literature.[5]

2.6 DISCRIMINATORS

The alignment and maintenance of the discriminators is fully described in the manufacturer's literature.[6] It should be noted that if tubes in the frequency selective circuitry are changed, the linearity will probably be affected.

3. CONTROL EQUIPMENT

3.1 RUDDER CHANNEL

3.1.1 Rudder Control Panel

The three types of rudder controls are used in a voltage divider network of the rudder channel subcarrier oscillator. To switch from one type of control to another without recalibration, the controls must be matched to about $\pm$ 0.1 percent for equal end resistance and for total resistance. If any component has to be replaced, the entire circuit should be checked and retrimmed, if necessary.

3.1.2 Subcarrier Circuits

Adjust the subcarrier oscillators as described in Section IV, 2.1.1. Adjust the front panel controls of the discriminator as described in the calibrating procedure, Section III, 2.2.1. If internal discriminator adjustments are required, they should be made in accordance with procedures described in Reference 6.

3.1.3 Rudder Servo

The adjustments to the rudder servo should be made in the following order; however, steps may be omitted if it is felt that only certain controls require adjustment:

a. With the power turned OFF, mechanically position the rudder servo control potentiometer so that the slider is at the center of its range when the digital indicator on the servo is at zero.

b. Adjust the cams for the limit switch (Figure 44) so that the switch opens at $\pm$ 47 degrees or at smaller angles if rudder throw is limited.

c. Connect the servo unit to the amplifier and set the circuit selector to the WIRE CONTROL, VELOCITY position. Connect a 5000-ohm multiturn potentiometer to the input circuit for position control. See Figure 42 for connections.

d. Disconnect the jumper shown in Figure 41 to remove servo motor power.

e. Connect an oscilloscope to one of the terminals marked G on the A-19 transformer.

f. Turn the power ON and manually rotate the servo shaft to the 0-degree position as indicated on the digital indicator.

g. Adjust the multiturn control potentiometer for minimum signal on the oscilloscope.

h. Adjust C-1 (Figure 41) for minimum quadrature signal. Readjust the control potentiometer slightly if necessary.

i. Move the oscilloscope input cable to the 0.47 μf condenser connected to the cathode of V3.

j. Adjust C2 (Figure 41) for minimum quadrature signal.

k. Connect an a-c voltmeter to junction Y, shown in Figure 42, which is between sections of R5. Set the VELOCITY dial to 50.

l. Observing the null indication on the oscilloscope and the digital position indicator on the servo unit, adjust R-1 (GAIN) and R-2 (CENTERING) so that the polarized relay contacts close (indicated by voltmeter reading) when the shaft is rotated 1 degree either side of the center (null) position.

m. Turn the power OFF, install the jumper, and then turn the power ON again.

n. Momentarily ground terminal 3 of TA-40001. If the servo motor tends to run in either direction, adjust resistor R7 (Figure 41) so that the motor does not run while terminal 3 is grounded.

o. Turn the CONTROL SELECTOR switch to the STD position and place a 100 pound-inch dead-weight torque load on the servo. Check the run-in rate for raising a load in clockwise and counter-clockwise directions. If the run-in rates are different, adjust R-4 (Figure 41) for fastest and approximately equal run-in rates.

p. Remove load and check damping for STD and VEL positions of SELECTOR switch. If necessary adjust R-3 or R-6 for desired degree of damping.

q. The gear train in the servo unit should be periodically lubricated with a small amount of Lubriplate.

3.2 PROPULSION CHANNELS

3.2.1 Propulsion Control Panel

There are no electrical adjustments on the propulsion control panel. Forward and reverse sections of the potentiometers are padded for equal total resistance when installed. Mechanical adjustments are provided for alignment of the potentiometers to the control levers. Adjustments are also provided for the microswitches which control the propulsion reversing circuits. A small amount of powdered Molly-Coat should be applied to the control shafts for smooth operation. The + 150 volt leads to the potentiometers are fused to protect the resistance elements of the potentiometers.

3.2.2 Subcarrier Circuits

Adjust the subcarrier oscillators as described in Section IV, 2.1.1. With the motor-generator turned OFF, place the control lever at the "50 FORWARD" position and adjust the CF BAL control on the discriminator in the model for zero current as indicated by the meter.

3.2.3 Error Regulator

There are three adjustable resistors in the error regulator circuitry. Adjustment will probably be required only if components are changed. When making these adjustments, a 30- to 50-ohm resistive load with a power rating of 3 kilowatts should be connected to the output of the motor-generator in place of the propulsion motor. NOTE: The motor-generator output should be kept low or at zero except for short periods while making these adjustments.

1. Set the range switch on the error regulator to the 300-volt position.

2. Adjust the propulsion control lever for zero output current on the meter of the discriminator.

3. Adjust the ZERO control (R-1, Figure 58) for a motor-generator output of 150 volts.

4. Check the output voltage versus control lever position. Zero on the control lever should produce zero output and 100 on the lever should produce an output of 300 volts. If the range is not correct, adjust the SENS control on the discriminator.

5. Connect a test set such as a Simpson Model 260 to the BAL TEST terminals on the printed circuit board, Figure 57. Set the meter on the 2.5-volt d-c scale and set the propulsion control lever for a 150-volt output. Adjust R-3 (on the printed circuit board, Figure 57) for zero voltage on the test set.

6. Connect an oscilloscope across the resistive load. Set the RANGE switch on the error regulator for 150-volt output. Introduce a transient into the system by rapidly moving the control lever within the central portion of its range. Observe the transient response on the oscilloscope. If necessary, adjust R-2 (GAIN) for a damping factor of about 0.4 to 0.6, i.e., 10 to 20 percent overshoot.

7. The emitter current of the output stage may be monitored at the test points on the panel. A 5-volt drop across these points represents 1 ampere emitter current, which is approximately full drive to the motor-generator.

3.2.4 Spare ON-OFF Channel

No adjustments are required except the amplitude of the tone oscillator signal into the mixing network. See Section IV, 2.3, for details.

4. POWERING EQUIPMENT

4.1 ROTATING EQUIPMENT

a. Inspect commutators and collector rings on all machines to see that the surface is smooth and polished.

b. Check brushes on machines to see that they move freely and make firm and even contact with the commutator or collector rings. Keep a spare set of brushes on hand for each machine.

4.2 STARTING EQUIPMENT

Check time-delay relays to see that they operate at the proper time intervals indicated in Figure 50.

4.3 BATTERY CHARGER

Lubricate fan motor once a year and if charger is operated in dusty location, blow out dust and dirt as often as required.

4.4 BATTERIES

4.4.1 Charging

To protect rotating equipment which is subject to the full charging voltage, this voltage should be limited to 50 volts. The charging rates to be used when operating the models is posted on the battery charger.

If individual cells are removed from the tray, it is essential that the cells be supported before charging. This may be done by placing stiff fiberboard or plywood on the end faces of the cell or group of cells, parallel to the plates within the cell and clamping firmly, as with a C-clamp. Never charge an unsupported cell or cell group without lateral support.

If the battery is on constant float or trickle charge, the charger should be adjusted, with the battery in a full charged condition, so that the battery voltage will be maintained between a minimum of 1.37 and a maximum of 1.39 times the number of cells in the battery (49.3 to 50.1 volts for a 36-cell, 48-volt battery, etc.). This will keep the battery in a charged condition and minimize the frequency of water additions.

4.4.2 Electrolyte

The electrolyte in this battery is a solution of potassium hydroxide (KOH) having a normal specific gravity of 1.300 at 72°F. It has a freezing point of – 80°F. The specific gravity of the electrolyte does not change appreciably between charge and discharge.

The cells of the battery contain only a small amount of electrolyte. The electrolyte level should be checked only after the battery has been charged and water added as required, taking care not to overfill. Even in the fully charged condition, the level should be no higher than the red line which, in some types of cell, is only slightly above the plate tops. The reserve electrolyte type of cell construction has two red lines marked on the cell jar. The electrolyte level should be maintained between these red lines when the battery is in the charged condition. Whenever water is added, thoroughly soak and rinse the removed vent plugs with water before replacing. Very little water will be consumed if the battery is on constant trickle or float charge at the proper voltage.

In very small cells there is not sufficient electrolyte to take hydrometer readings. After some time in severe cycle service where electrolyte specific gravity is in doubt, invert the battery, draining all free electrolyte. Replace with new electrolyte of 1.300 specific gravity, which should be obtained only from the manufacturer.

When charging at high rates, the cells will gas rather vigorously when approaching full charge. This gassing will cause the electrolyte level to rise above the red line. This apparent excess electrolyte should not be removed as the level will drop back after the cells stand on open circuit following the charge.

A white crystalline deposit may appear on the cell tops. This is potassium carbonate which is noncorrosive and harmless. This should merely be brushed or washed off periodically.

Maintain the battery in a clean and dry condition externally. Carefully wipe off any spilled liquid.

WARNING: Sulfuric acid, as used in lead-acid batteries, will cause permanent damage to NICAD batteries. Therefore, do not add sulfuric acid to NICAD cells and do not use any tools, such as hydrometers or funnels, which have previously been used with lead-acid batteries.

Care should be taken to keep open flames or sparks from the battery particularly when it is on charge, as there is the possibility of hydrogen gas being generated in the electrolysis of water and the resulting danger of an explosion.

Do not spill electrolyte on clothes or the skin. In case of accident, wash with vinegar or saturated boric acid solution and rinse freely with water.

5. READOUT EQUIPMENT

5.1 RUDDER CHANNEL

5.1.1 Position

The alignment of the control and readout potentiometers on the servo unit is described in Section IV, 3.1.3. Information as to the adjustment of the telemetering equipment is described in the calibrating procedure, Section III, 2.2.2, and in Section IV, 2, which covers maintenance of telemetering equipment.

5.1.2 Running Time

There are no adjustments to this circuit except the amplitude control of the tone oscillator. Details on this adjustment are covered in Section IV, 2.3.

5.1.3 Port—Starboard Indicator

A microswitch on the servo unit is cam-actuated when the rudder passes the 0-degree position. The cam may be adjusted by loosening the set screw in the edge of the cam. The only other adjustment to this circuit is the amplitude control on the tone oscillator. See Section IV, 2.3, for details of this adjustment.

5.2 PROPULSION CHANNELS

The adjustment of the telemetering portions of these channels is described in Section IV, 2. The SENS controls on the readout circuit discriminators in the console should be turned fully clockwise. The system may be most easily checked by driving the pickup with a variable speed 0- to 3000-rpm motor and following the procedure outlined below.

a. Connect an oscilloscope to the digital output connector on the console and adjust R-1 (PORT) or R-2 (STBD) for stable operation of the Schmitt trigger over the entire speed range.

b. Connect a digital events-per-unit-time meter to the digital output connector on the console.

c. Set the meter range selector on the console to the 1500-rpm position. Using the digital indicator, adjust the motor speed to 1000 rpm. If the console meter indication is not correct, adjust the appropriate calibrating capacitor (Figure 19) for proper indication. Repeat the procedure for the 3000-rpm range using a motor speed of 2000 rpm. NOTE: If the capacitors will not cover the range or if both ranges are off in the same direction, R-4 or R-5 may be adjusted.

d. Check the accuracy of the console indicators at several points for each range. Accuracy should be better than $\pm$ 1.5 percent of full scale.

5.3 SPARE CHANNELS

The spare channels are simple analog and ON-OFF channels. The adjustment procedures are outlined in Section IV, 2.

6. POWER SUPPLIES

6.1 CONSOLE EQUIPMENT

The vacuum-tube power supplies for the console equipment have potentionmeters for adjustment of output voltage and balance controls for ripple reduction. Control numbers and

functions are indicated on the schematic drawings, Figures 24 and 27, and in the photographs, Figures 23 and 26. A test cable is provided for connecting the supplies to the console equipment while making these adjustments. The voltage controls should be adjusted first for proper output ($\pm$ 5-percent tolerance). Then a high gain oscilloscope should be connected to the output of the supply and the BALANCE control adjusted for minimum 120-cycle ripple.

6.2 MODEL EQUIPMENT

The transistor-regulated power supplies for the model equipment use one or two fuses for regulator protection. These fuses must be of the quick blow type and oversize fuses must not be used. The components in the regulator circuits may be checked or replaced by removing the base section of these units. The voltage tolerance of these units is $\pm$ 5 percent.

7. BLOWER

The blower at the rear of the console uses a replaceable filter element. The element should be replaced when the indicator on the blower panel reaches the red line. The blower motor has two oil fittings which should be lubricated with SAE 20 oil every 6 months.

PART V

BLOCK AND SCHEMATIC DIAGRAMS, GRAPHS, AND PHOTOGRAPHS

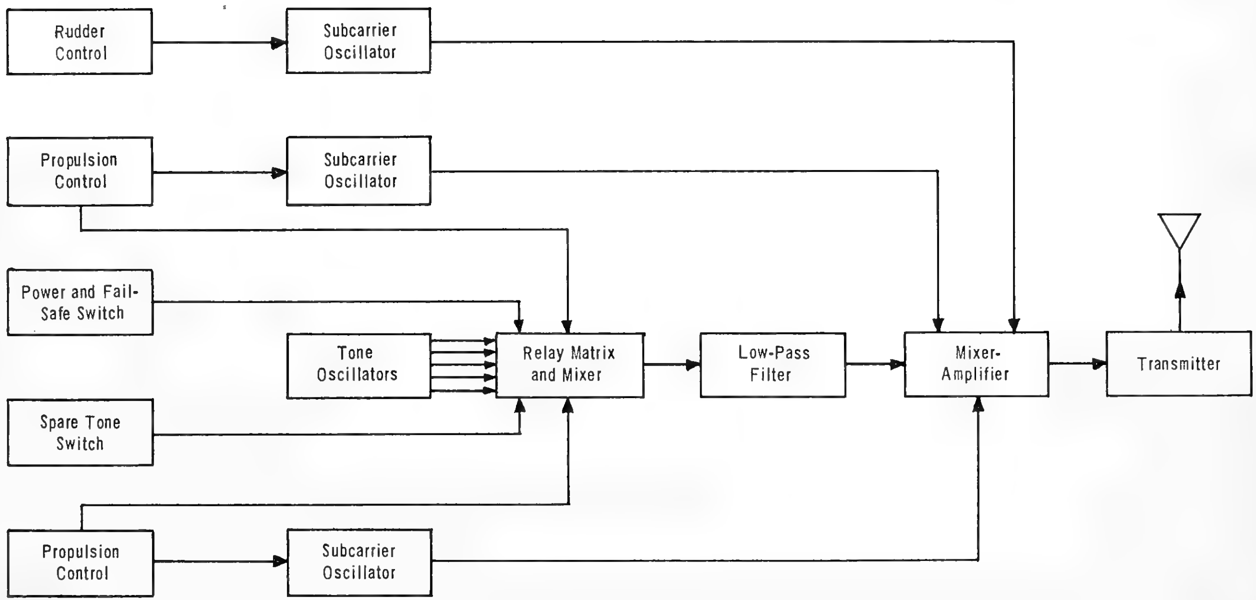


Figure 1 – Control Equipment, Console, Block Diagram

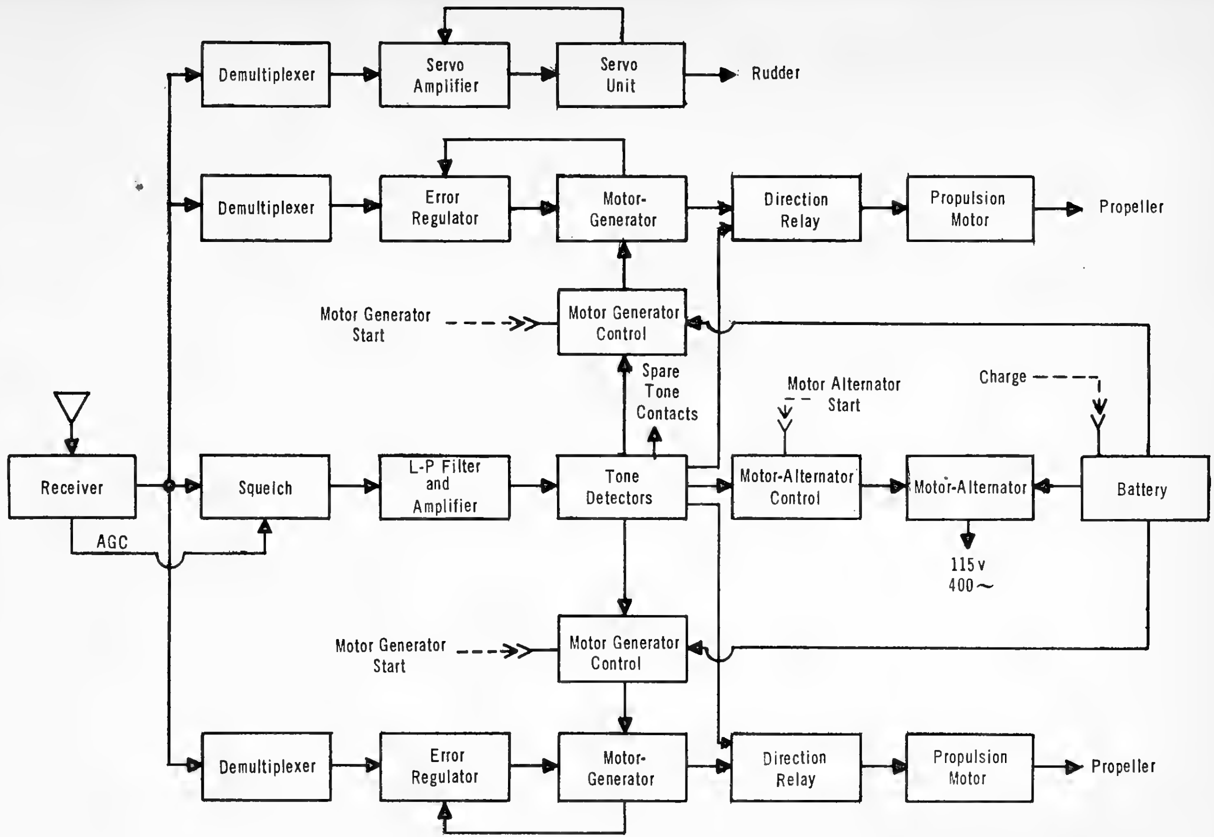


Figure 2 – Control Equipment, Model, Block Diagram

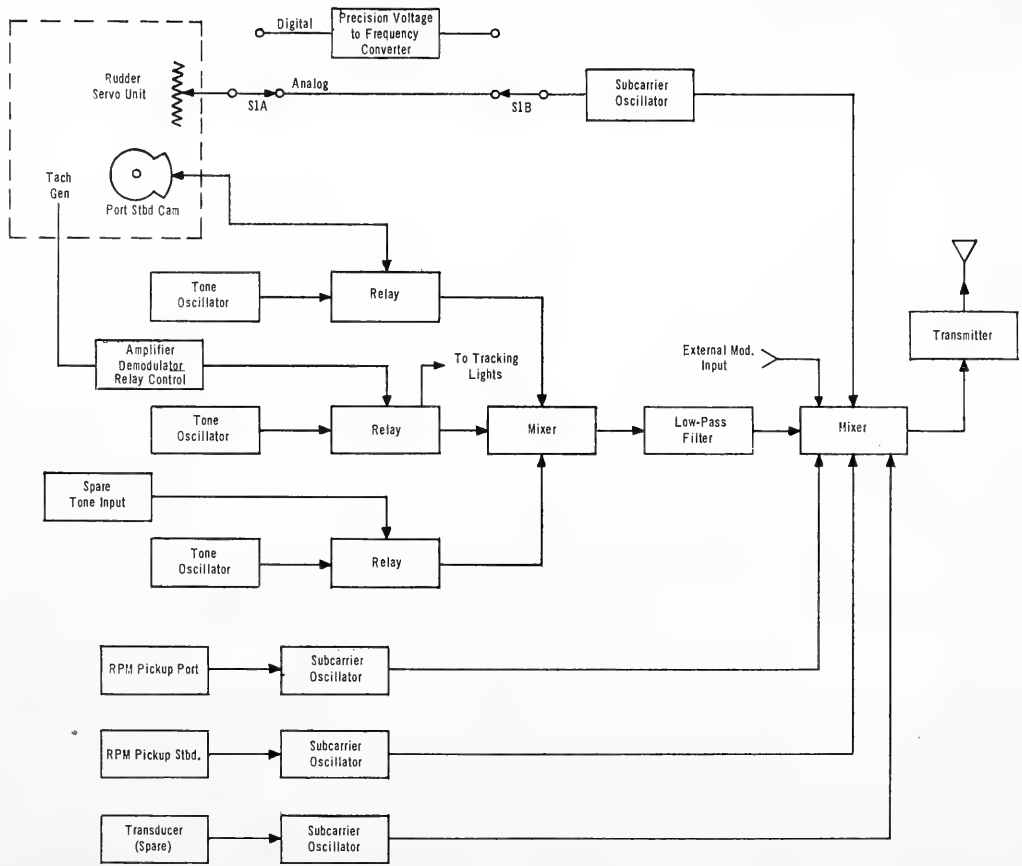


Figure 3 – Readout Equipment, Model, Block Diagram

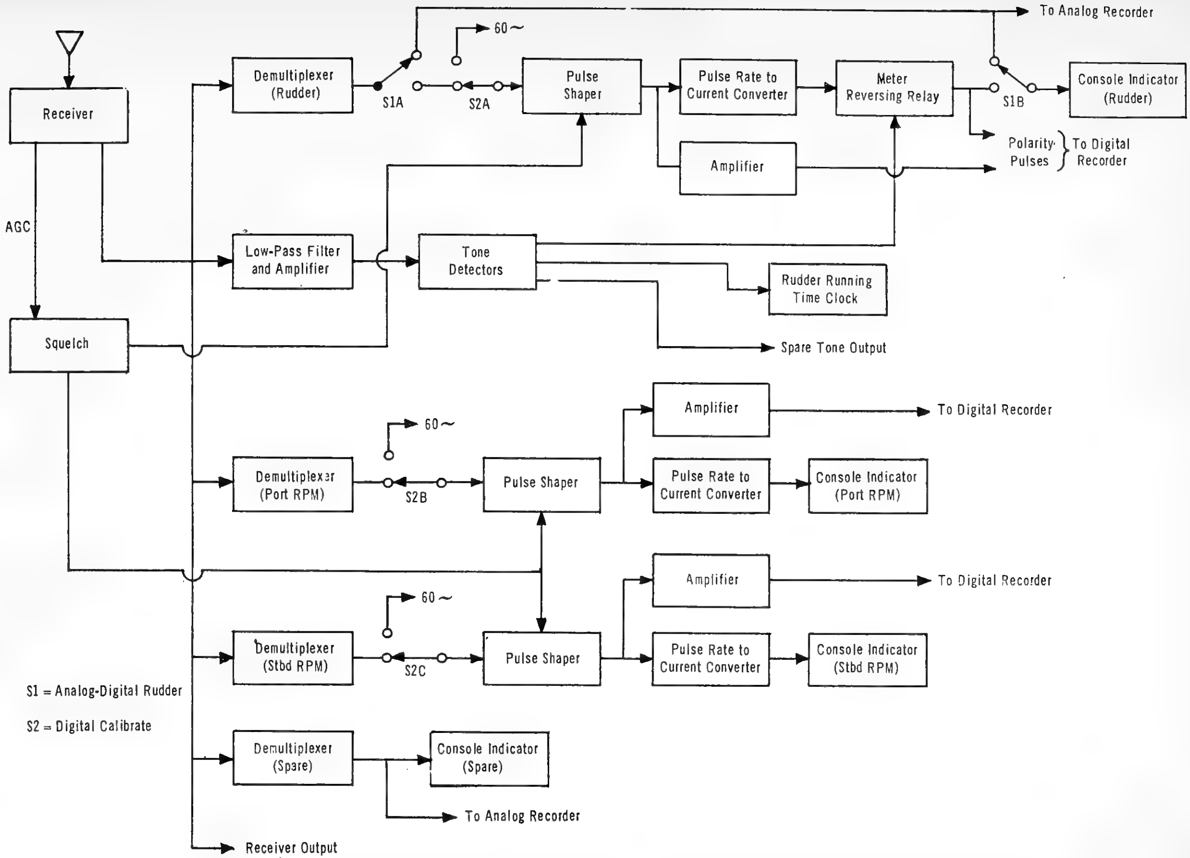


Figure 4 – Readout Equipment, Console, Block Diagram

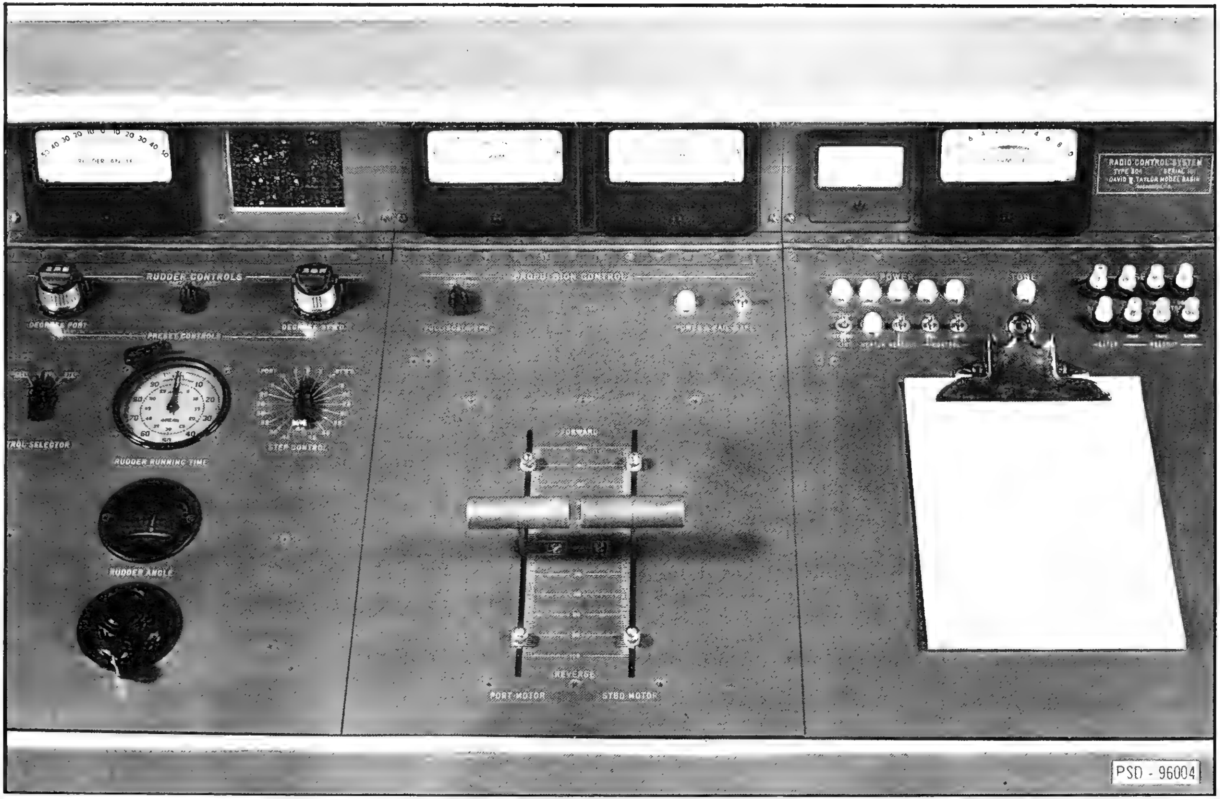


Figure 5 – Control Panel of Console

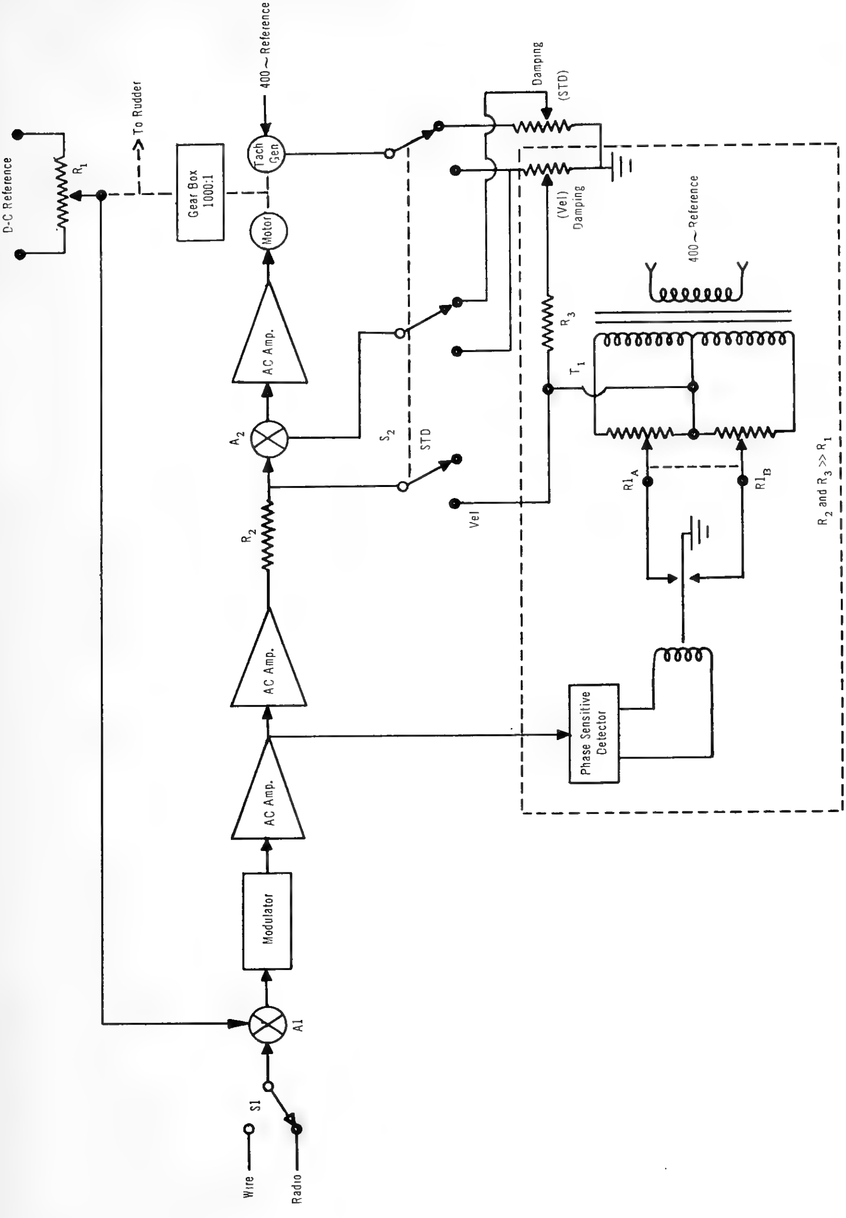


Figure 6 — Rudder Servo System, Block Diagram

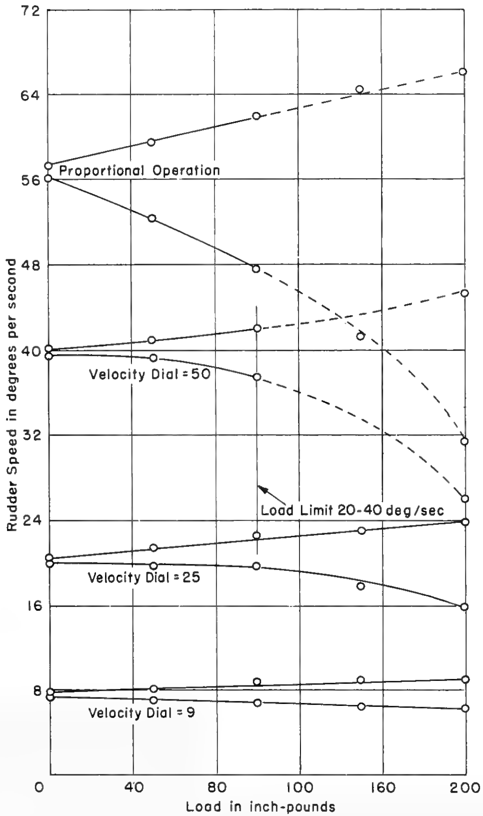


Figure 7 – Rudder Servo System, Speed-Load Curves

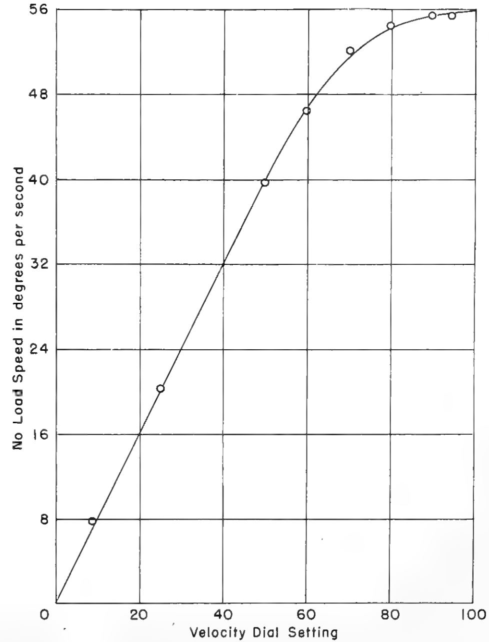


Figure 8 – Rudder Servo System, Dial Setting versus Servo Speed for Velocity Stabilized Operation

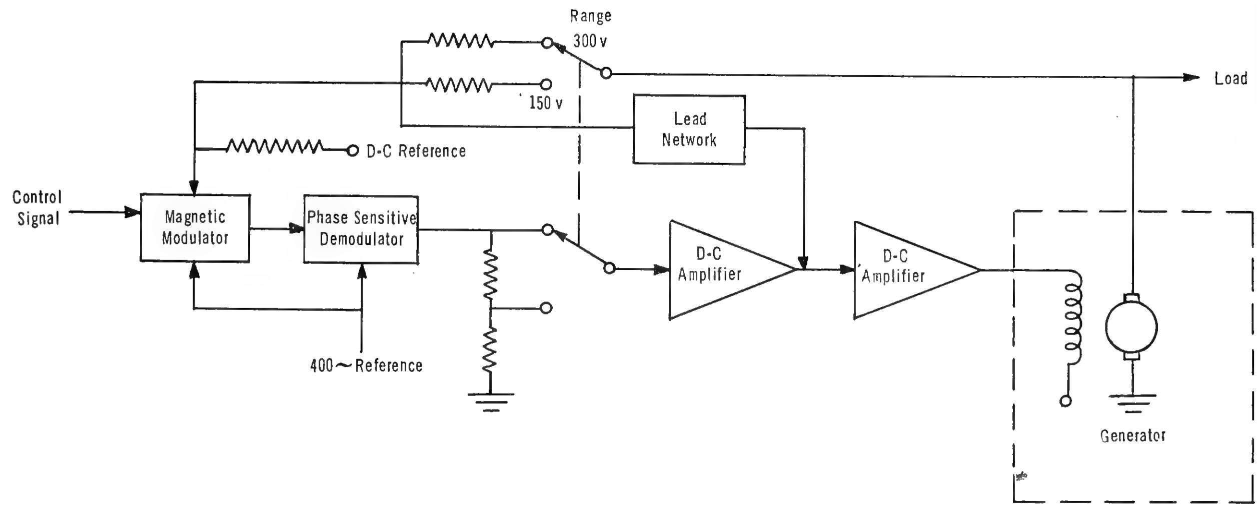


Figure 9 – Error Regulator, Block Diagram

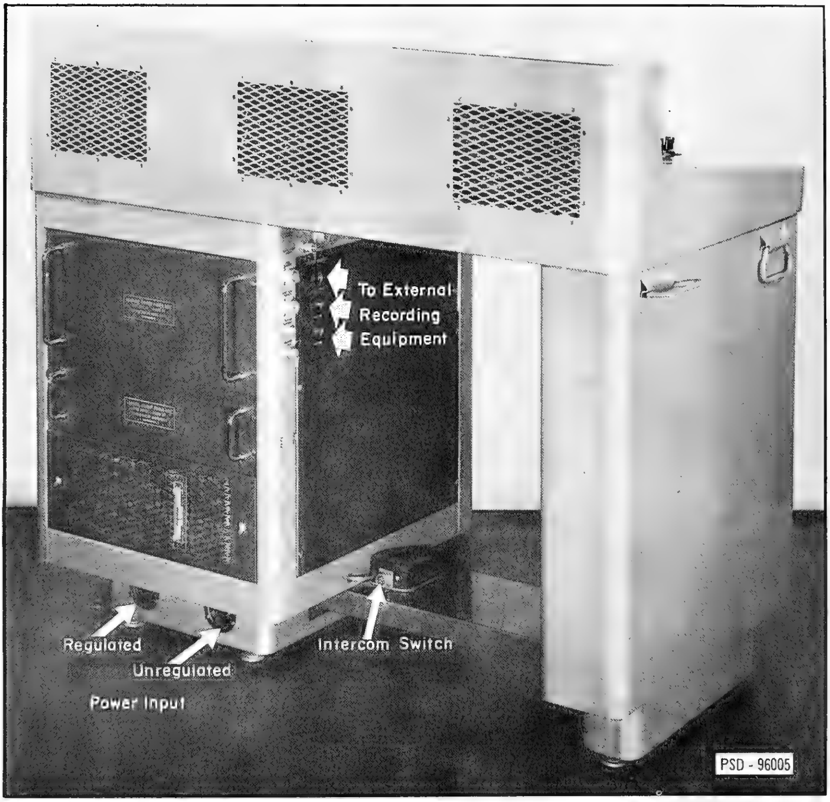
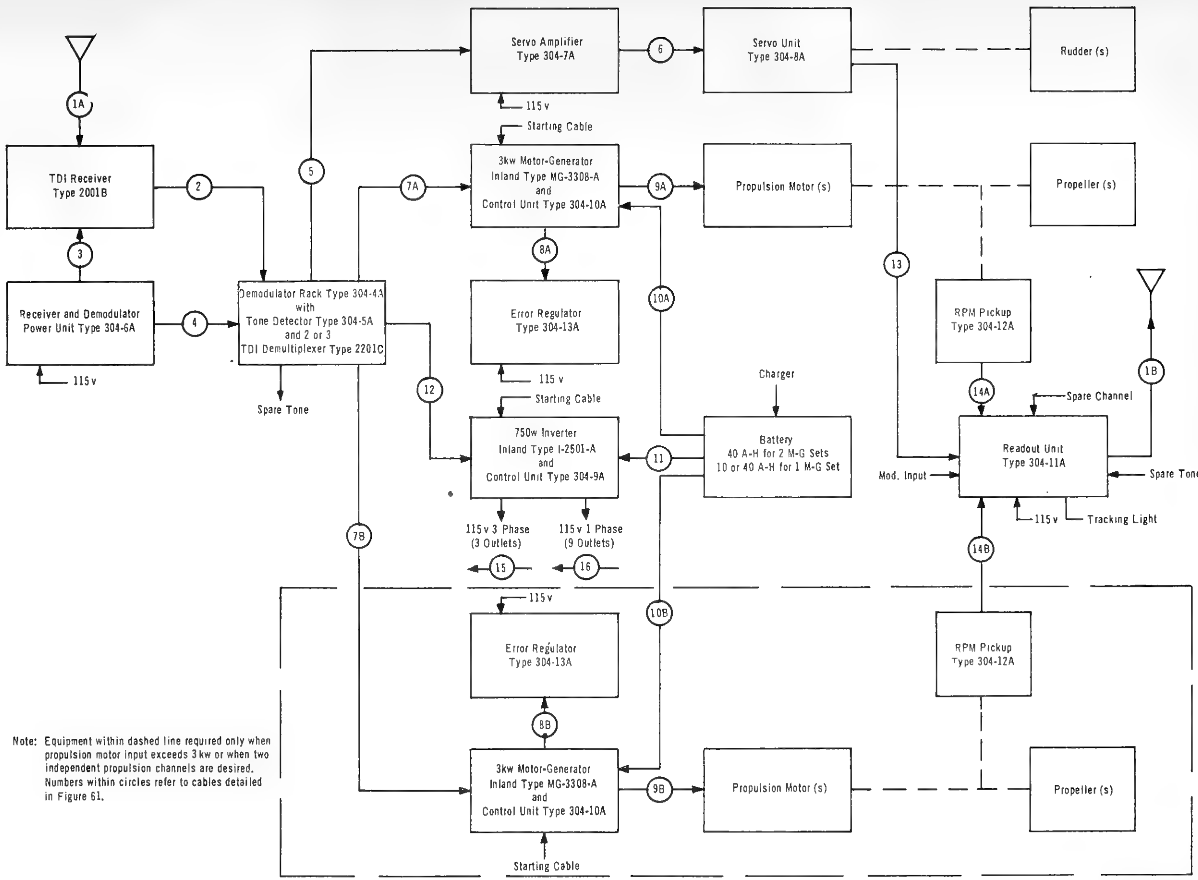


Figure 10 – Console, Rear View, Showing Power Input Connectors, Connectors for External Circuitry, and Foot Switch for Intercommunications System



Note: Equipment within dashed line required only when propulsion motor input exceeds 3 kw or when two independent propulsion channels are desired. Numbers within circles refer to cables detailed in Figure 61.

Figure 11 – Interunit Cabling, Schematic Diagram

Figure 12 – Console Front View with Control Panels and Control and Readout Unit Drawer Open

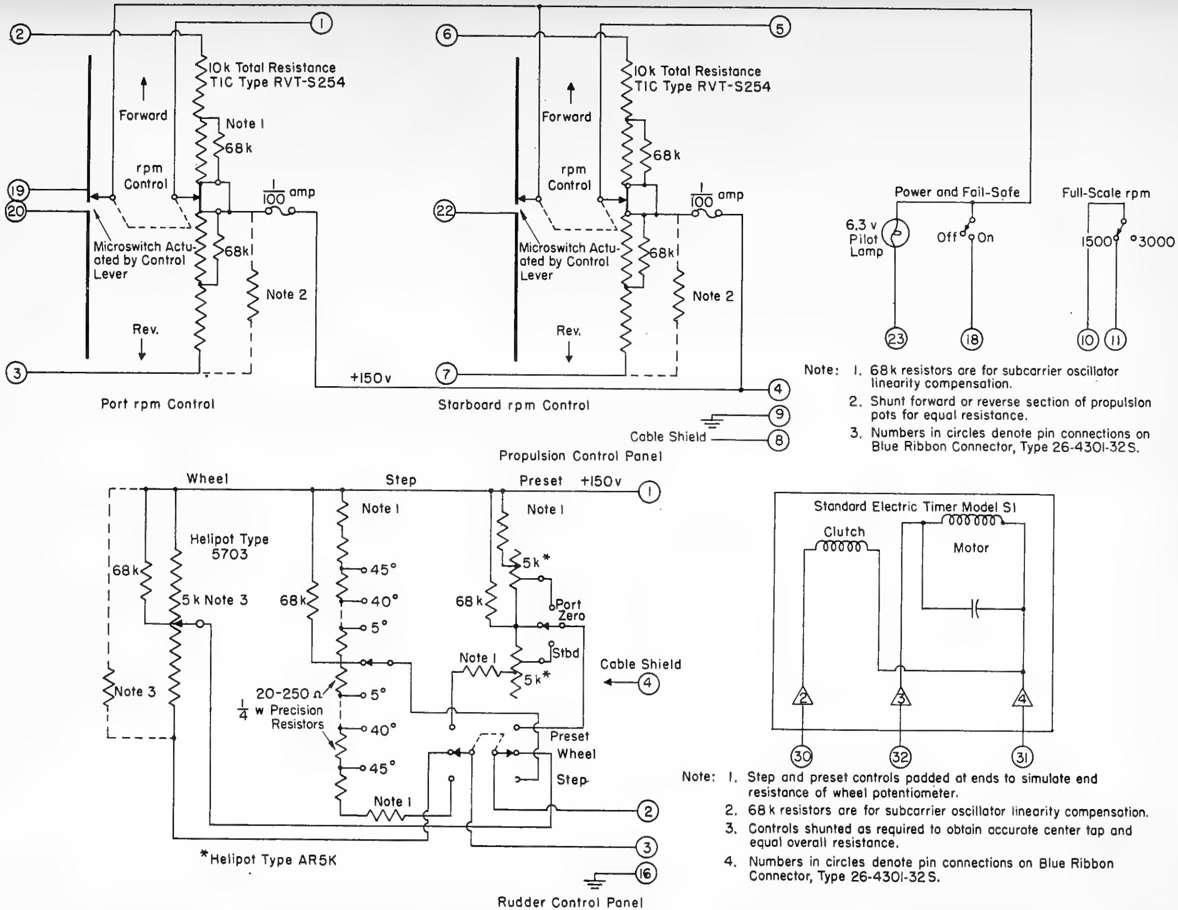
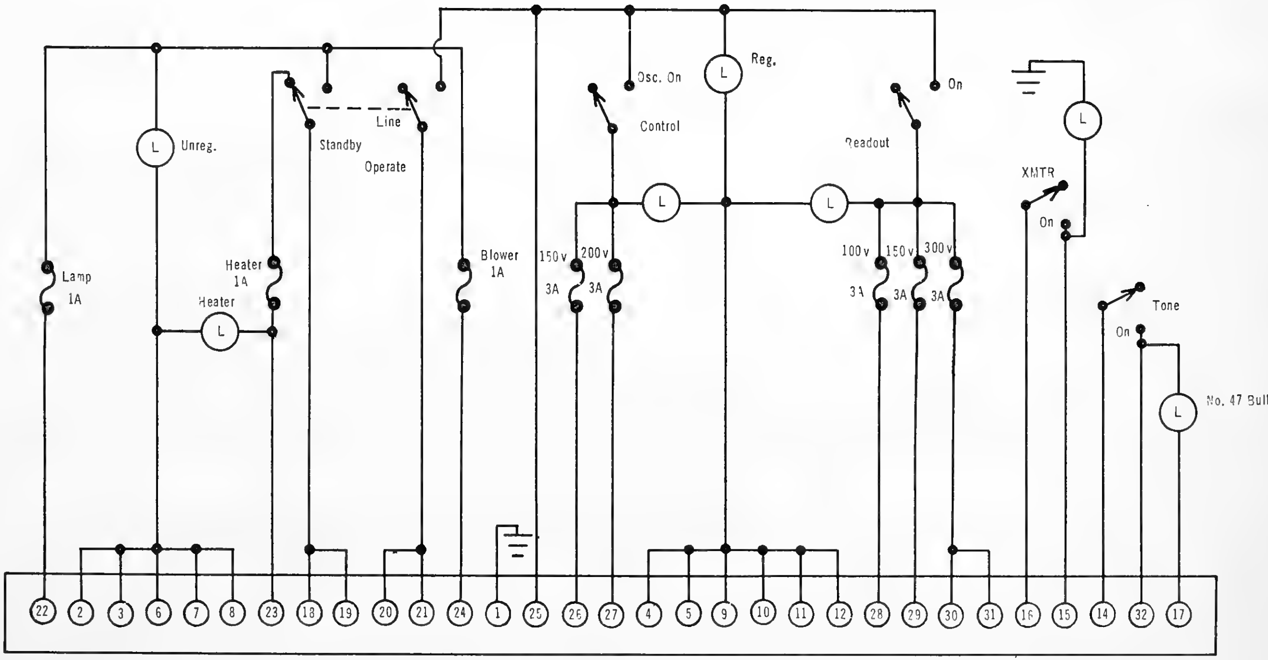


Figure 13 – Propulsion and Rudder Control Panels, Schematic Diagram



Note: 1. All fuses mounted in indicating type fuseholders.
2. All pilot lights 115 v neon type except as indicated.

Amphenol 26-4301-32S

Figure 14 – Power Control Panel, Schematic Diagram

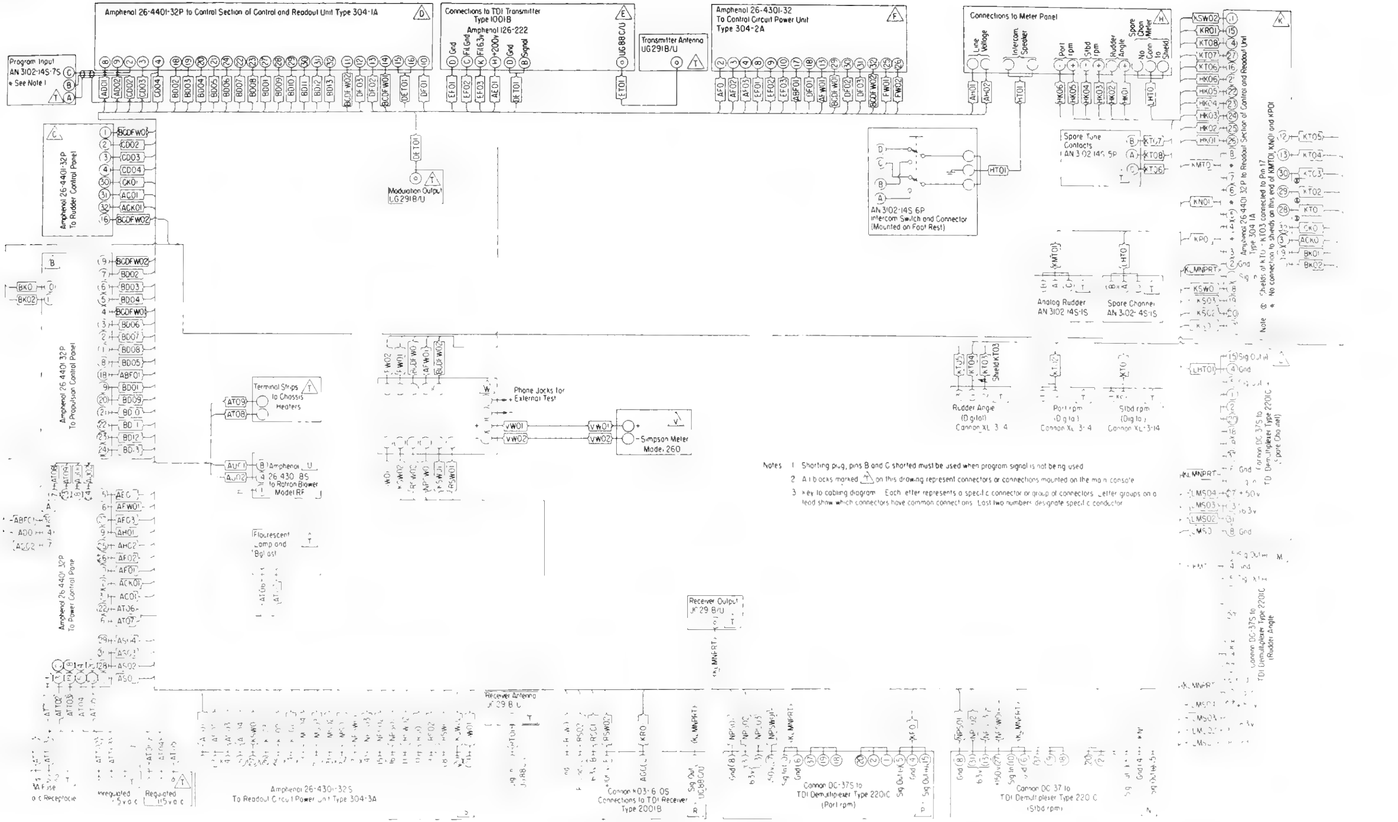
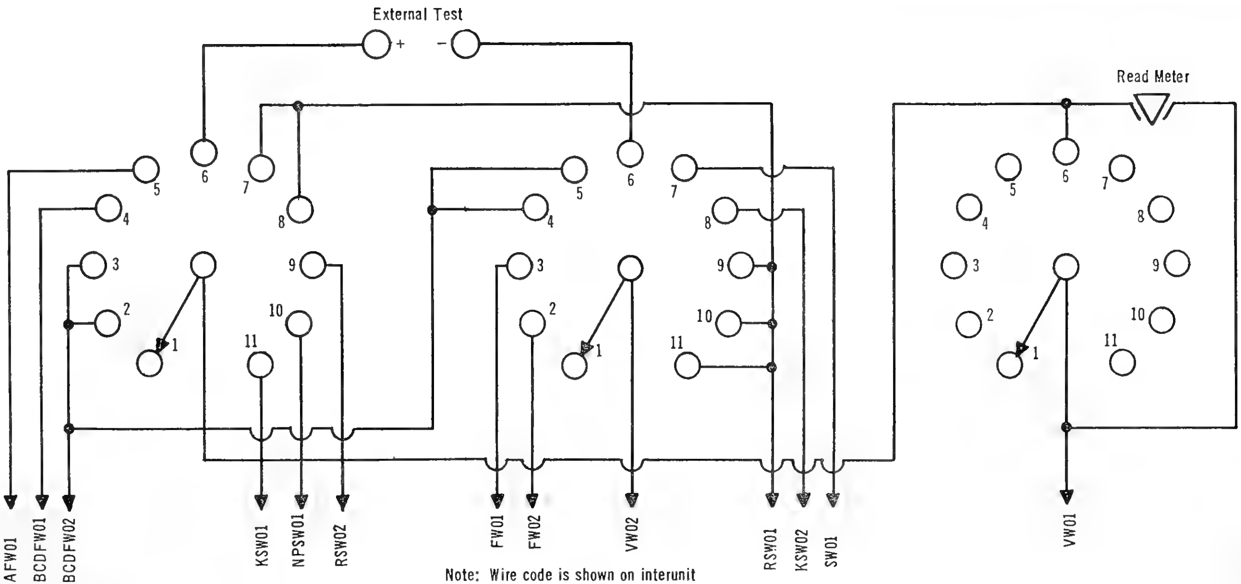


Figure 15 – Interunit Cabling of Console, Schematic Diagram



Note: Wire code is shown on interunit Cabling Diagram

Switch Position	Circuit	
1	Off	
2	-87 V	Control
3	-150 V	Control
4	+150 V	Control
5	+200 V	Control
6	Ext.	
7	-87 V	Readout
8	-150 V	Readout
9	+100 V	Readout
10	+150 V	Readout
11	+300 V	Readout

Figure 16 – Console Test Panel, Schematic Diagram

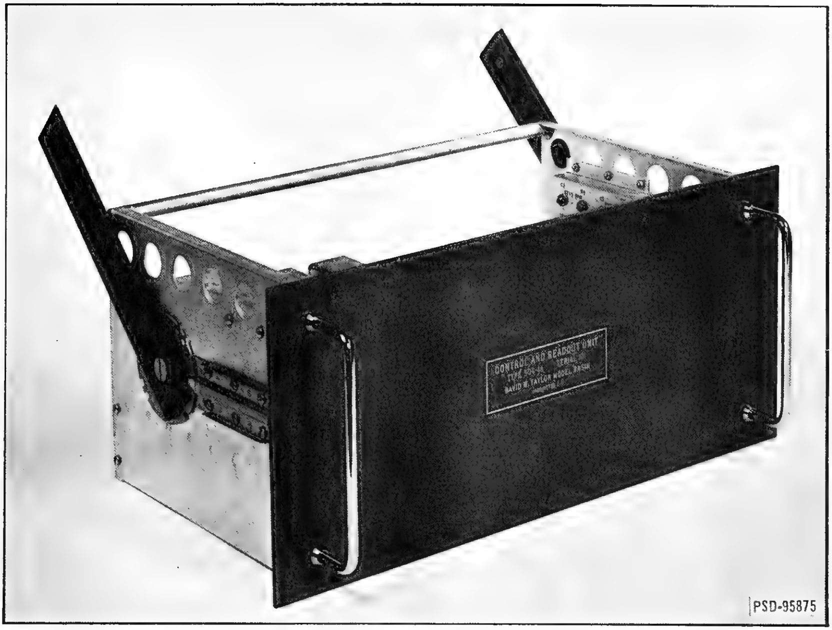


Figure 17 – Control and Readout Unit Type 304-1A, Front Oblique View

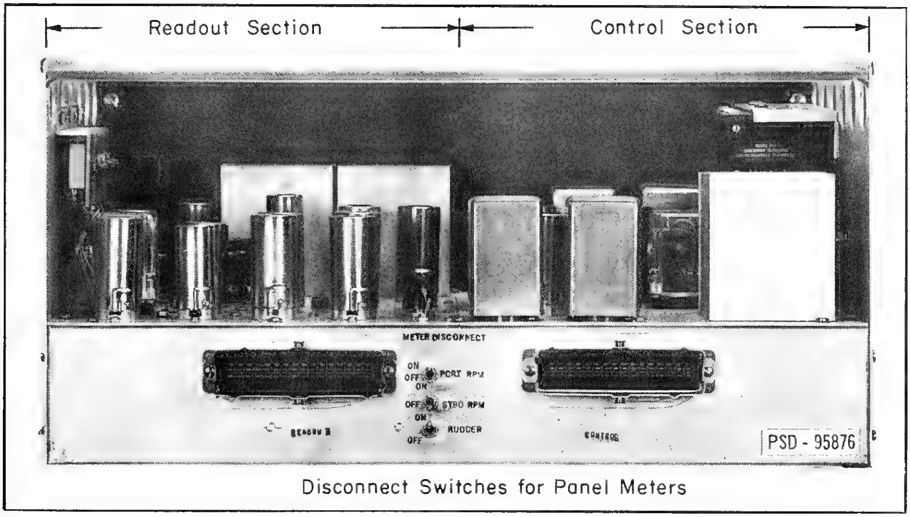


Figure 18 – Control and Readout Unit Type 304-1A, Rear View

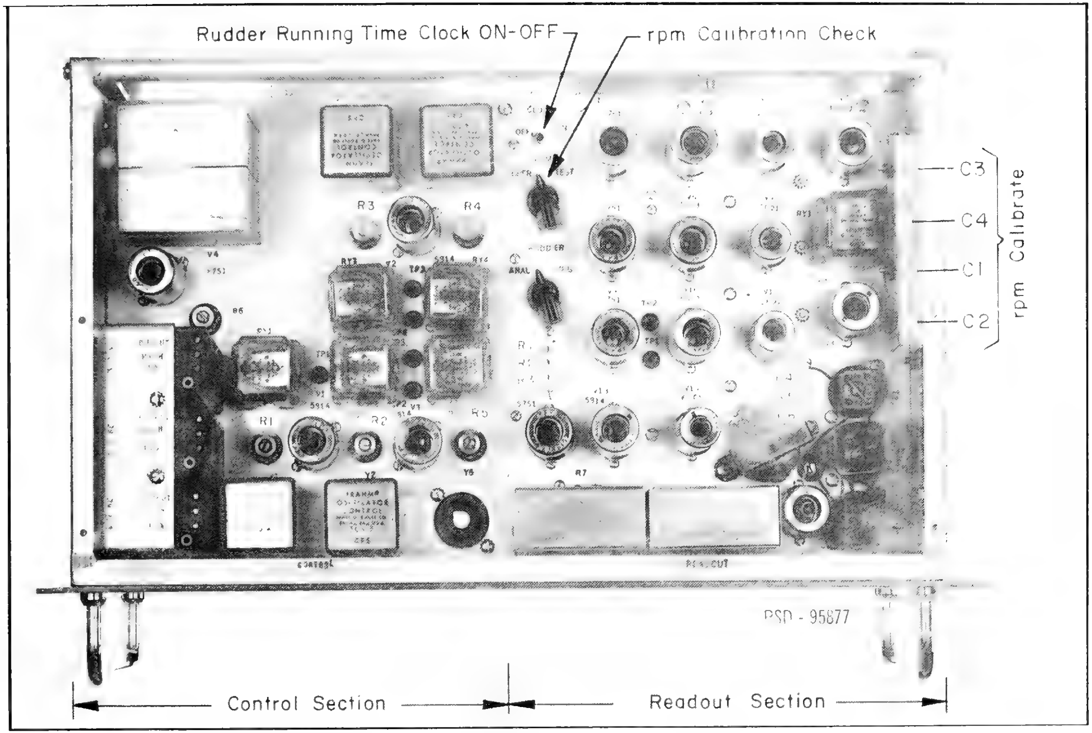


Figure 19 – Control and Readout Unit Type 304-1A, Top View

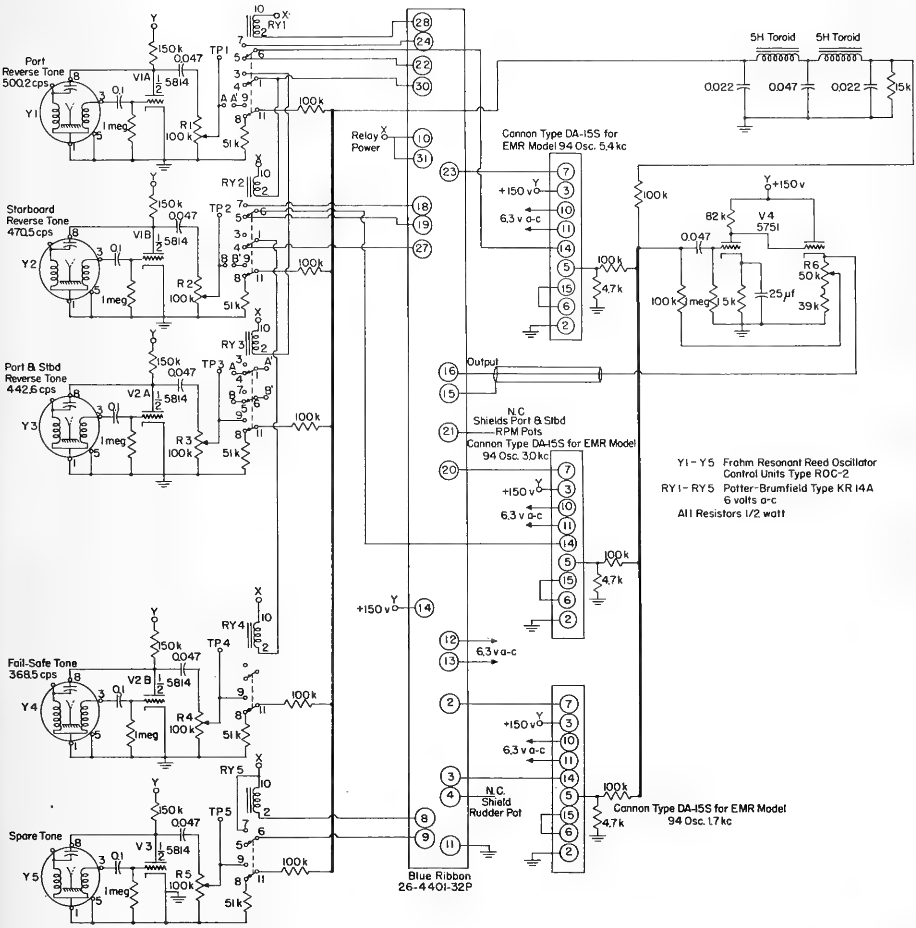
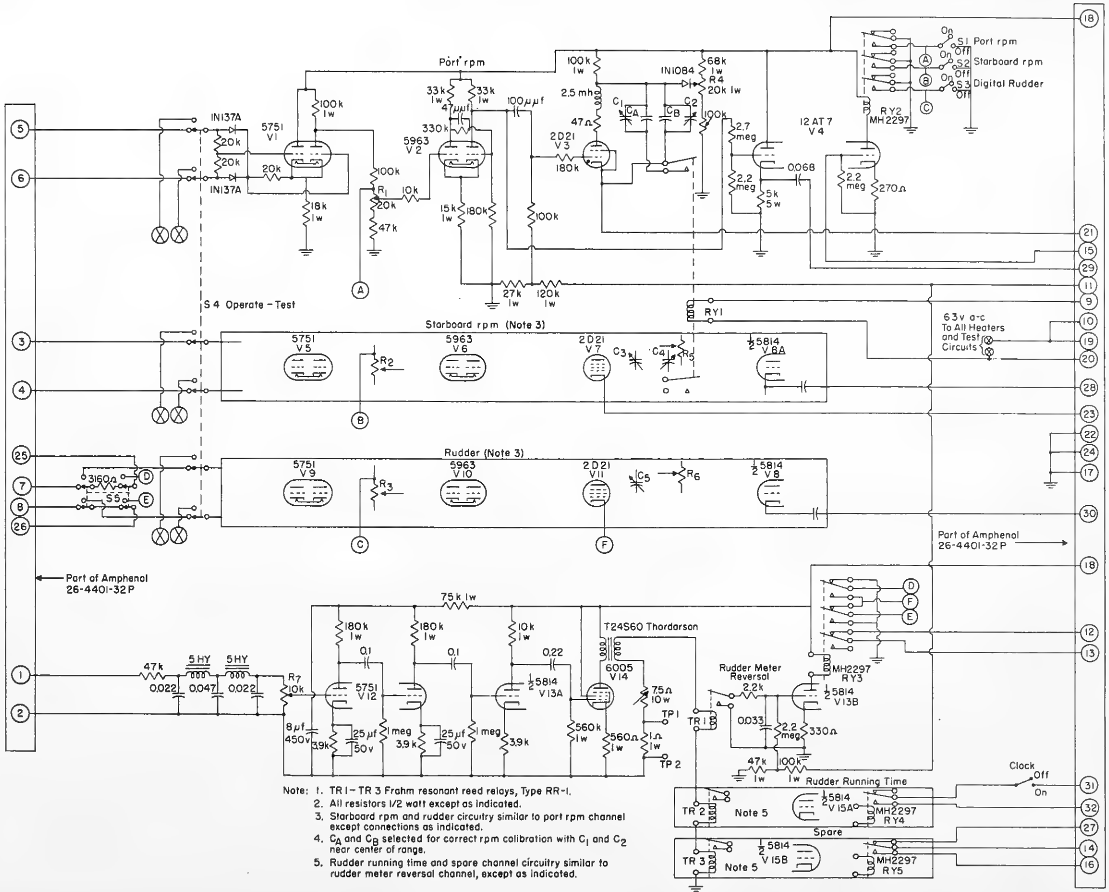


Figure 20 – Control and Readout Unit Type 304-1A, Control Section, Schematic Diagram



Note:
1. TR1 – TR3 Frahm resonant reed relays, Type RR-1.
2. All resistors 1/2 watt except as indicated.
3. Starboard rpm and rudder circuitry similar to port rpm channel except connections as indicated.
4. C_A and C_B selected for correct rpm calibration with C_1 and C_2 near center of range.
5. Rudder running time and spare channel circuitry similar to rudder meter reversal channel, except as indicated.

Figure 21 – Control and Readout Unit Type 304-1A, Readout Section, Schematic Diagram

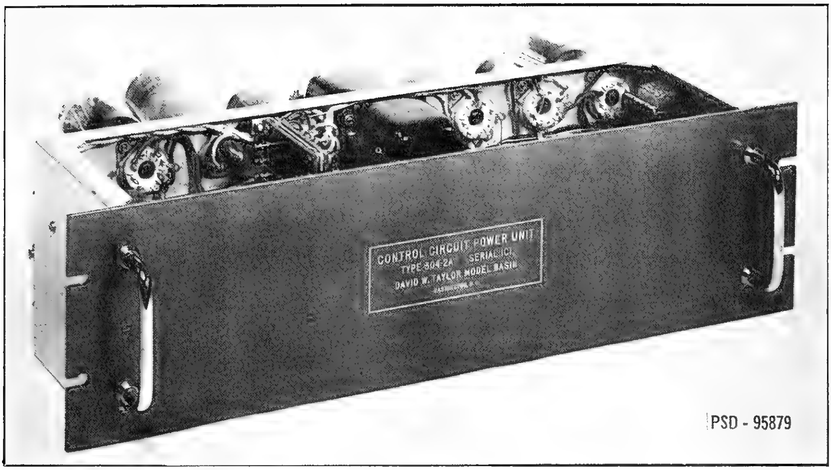


Figure 22 – Control Circuit Power Unit Type 304-2A, Front Oblique View

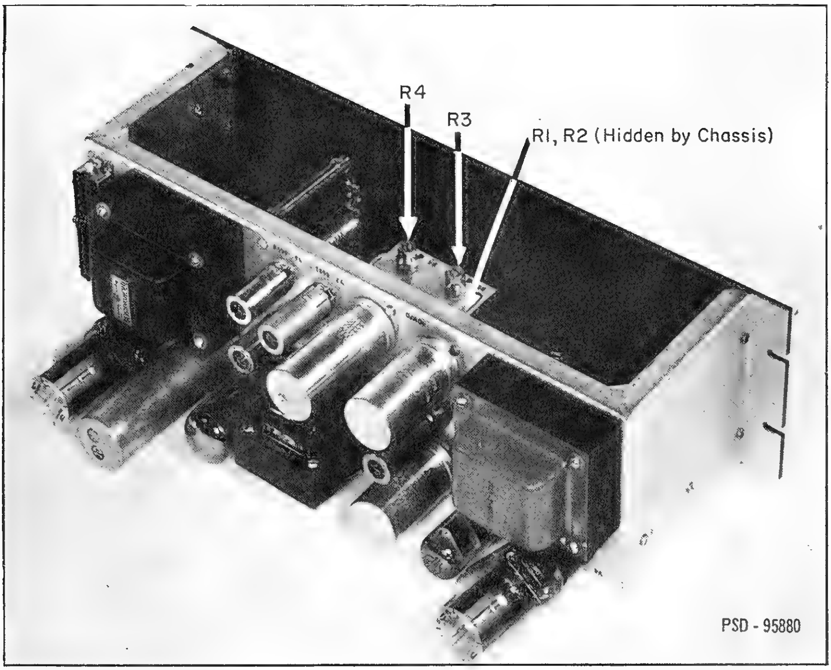


Figure 23 – Control Circuit Power Unit Type 304-2A, Rear Oblique View

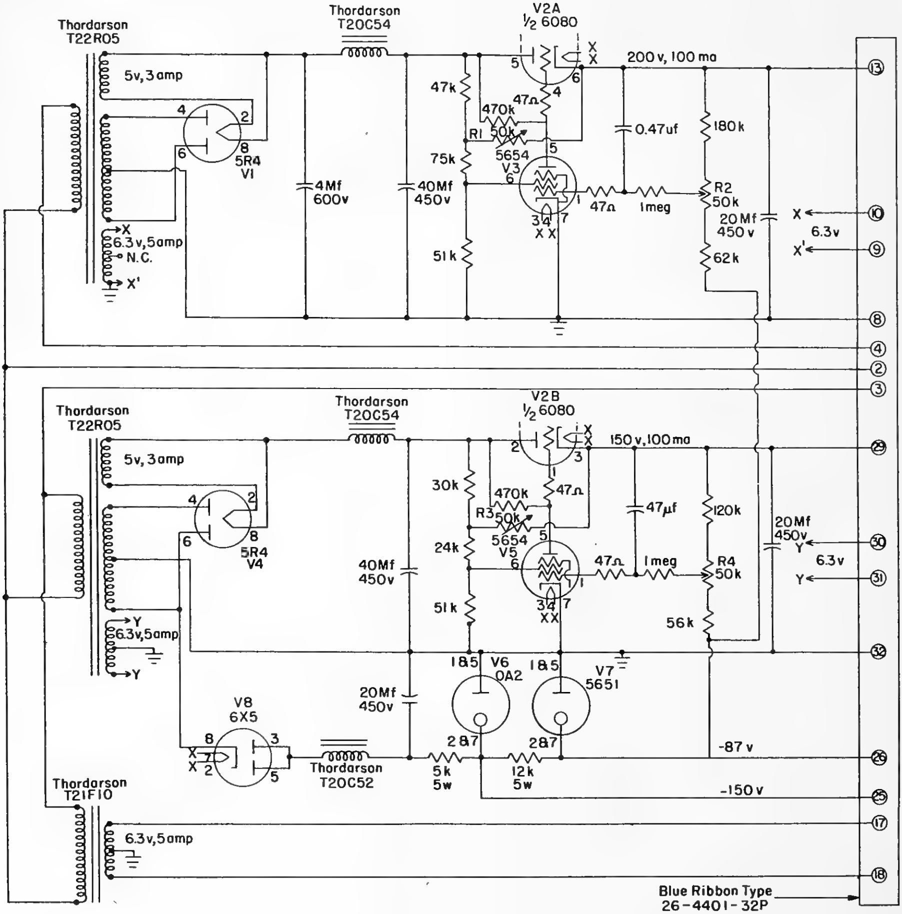


Figure 24 – Control Circuit Power Unit Type 304-2A, Schematic Diagram

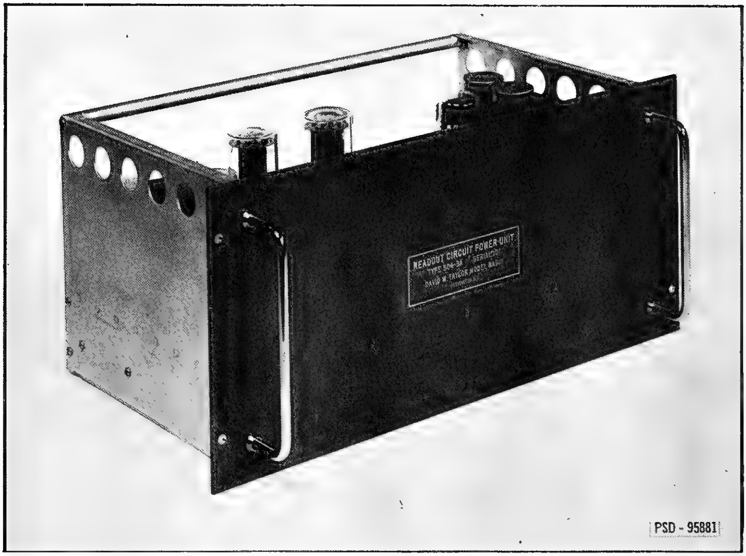


Figure 25 – Readout Circuit Power Unit Type 304-3A, Front Oblique View

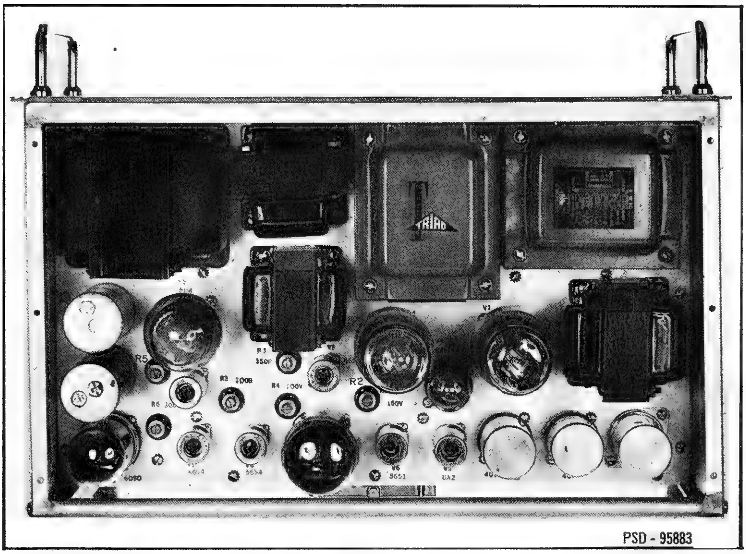


Figure 26 – Readout Circuit Power Unit Type 304-3A, Top View

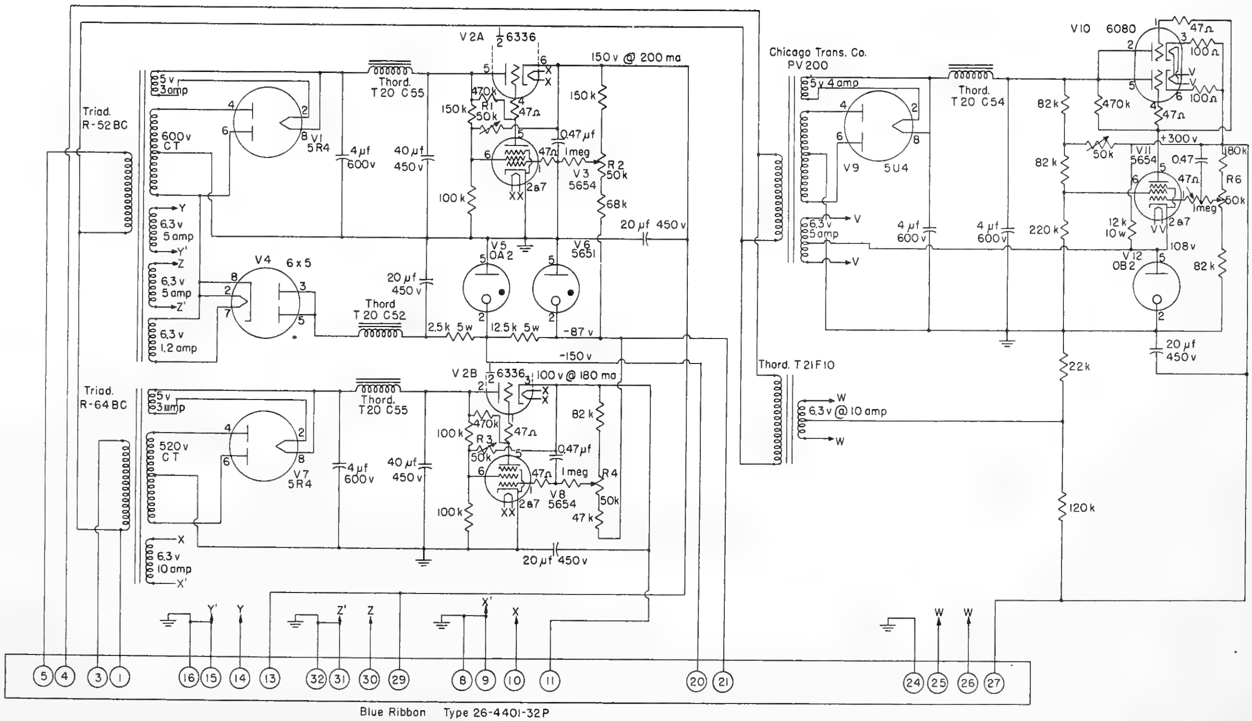


Figure 27 – Readout Circuit Power Unit Type 304-3A, Schematic Diagram

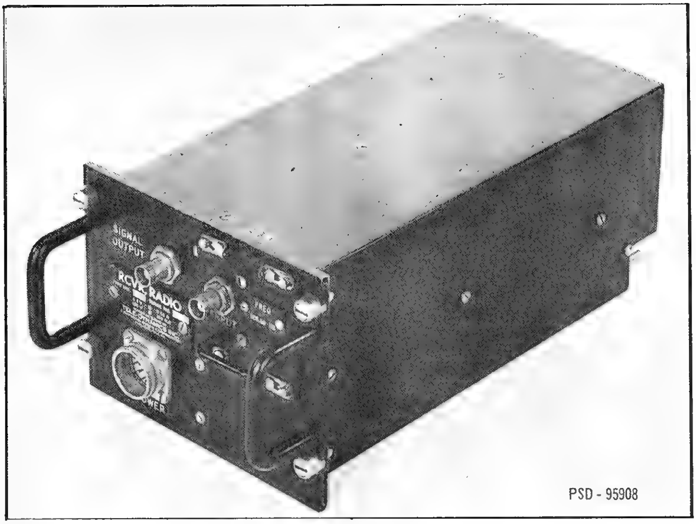


Figure 28 – Receiver, Tele-Dynamics Type 2001B, Front Oblique View

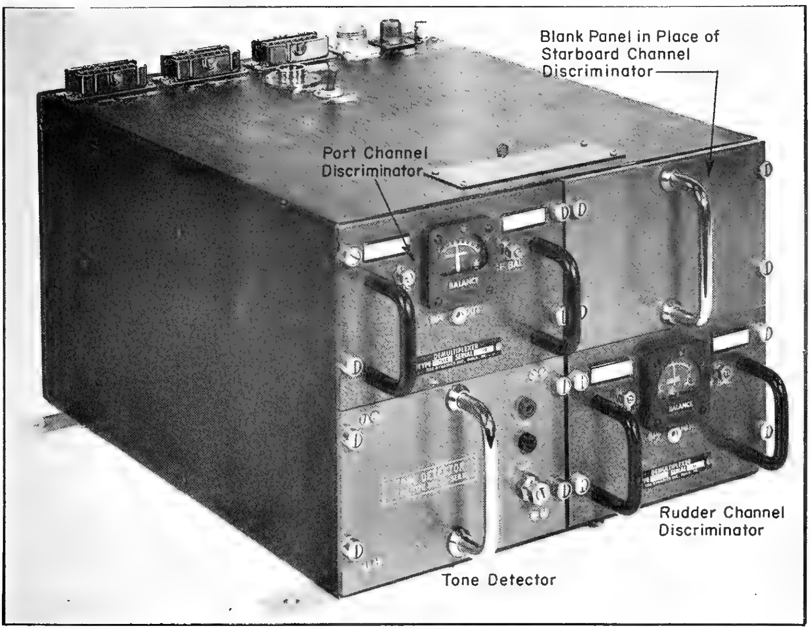


Figure 29 – Demodulator Rack Type 304-4A, Front Oblique View

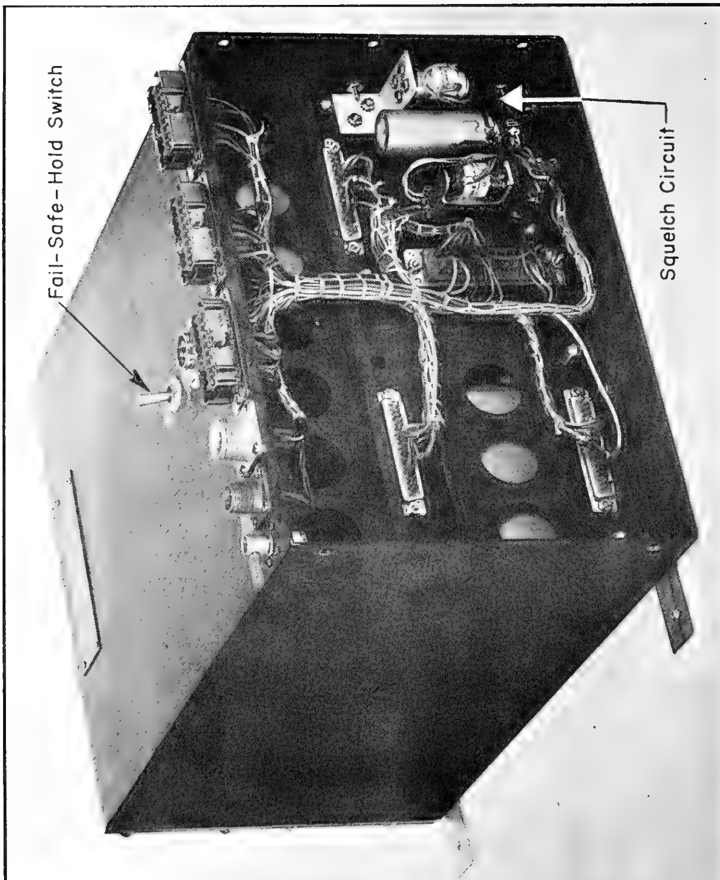


Figure 30 – Demodulator Rack Type 304-4A, Rear Oblique View

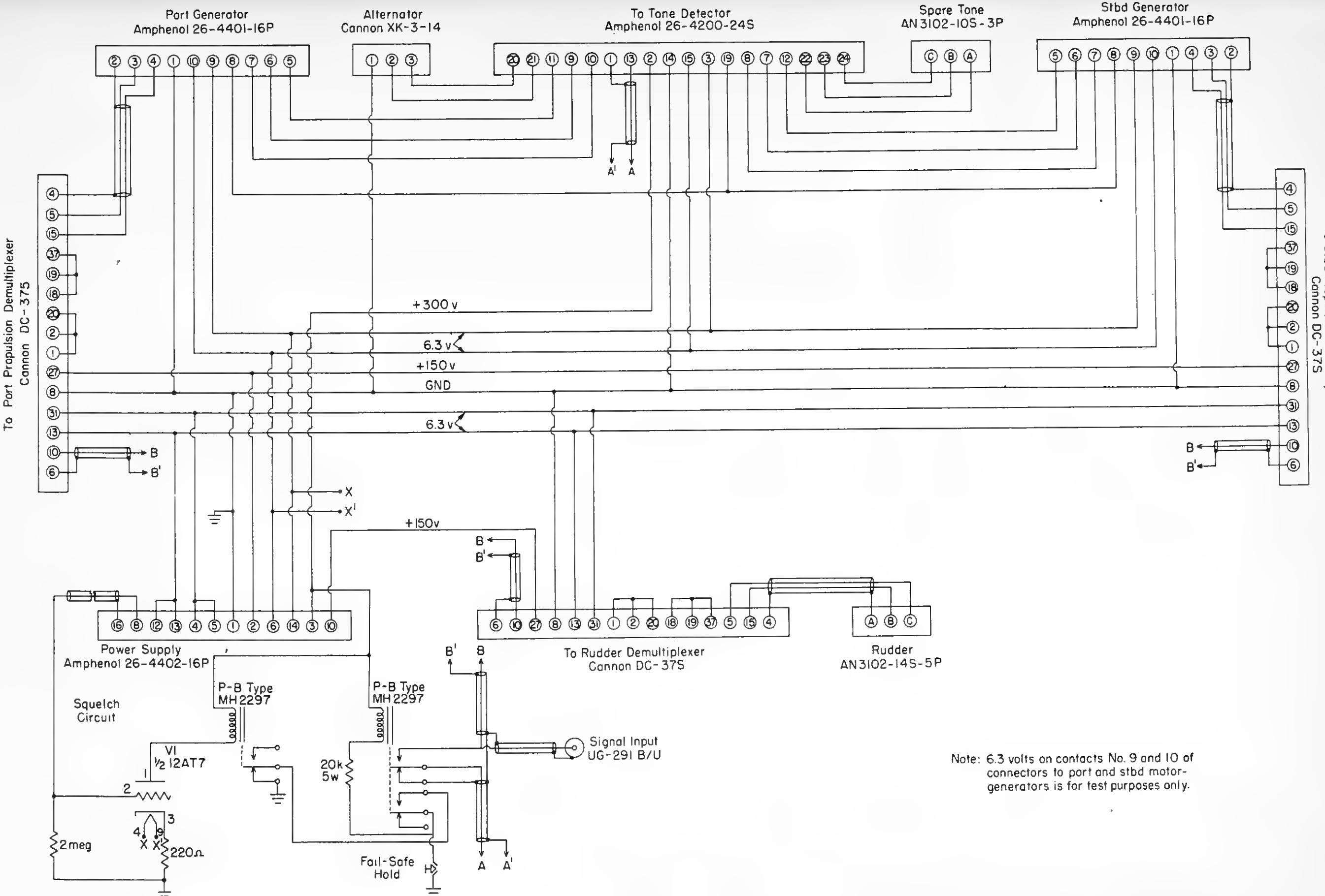


Figure 31 – Demodulator Rack Type 304-4A, Schematic Diagram

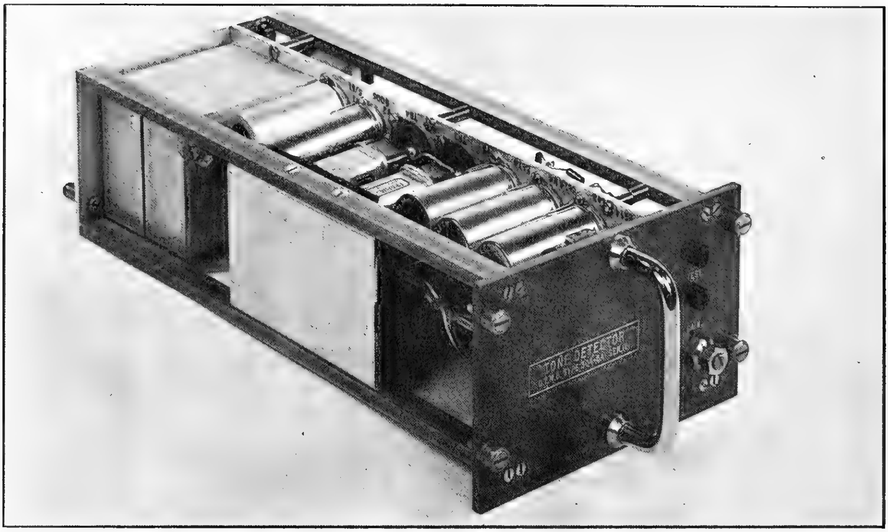


Figure 32 – Tone Detector Type 304-5A, Front Oblique View

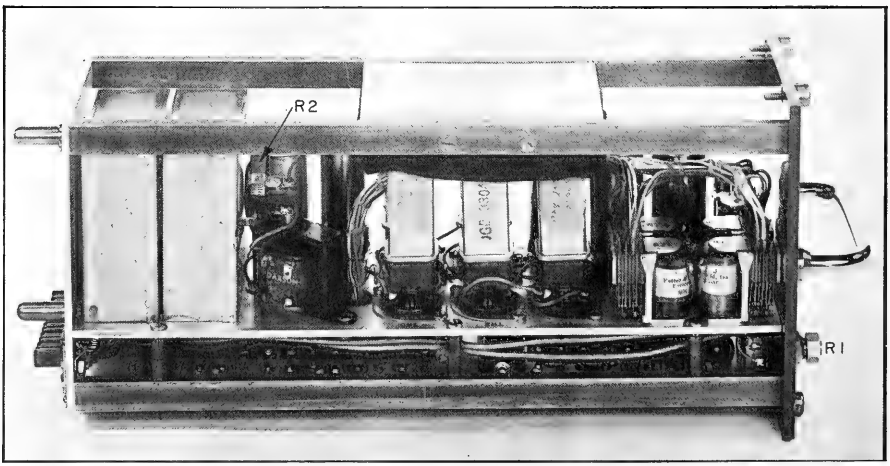


Figure 33 – Tone Detector Type 304-5A, Side View

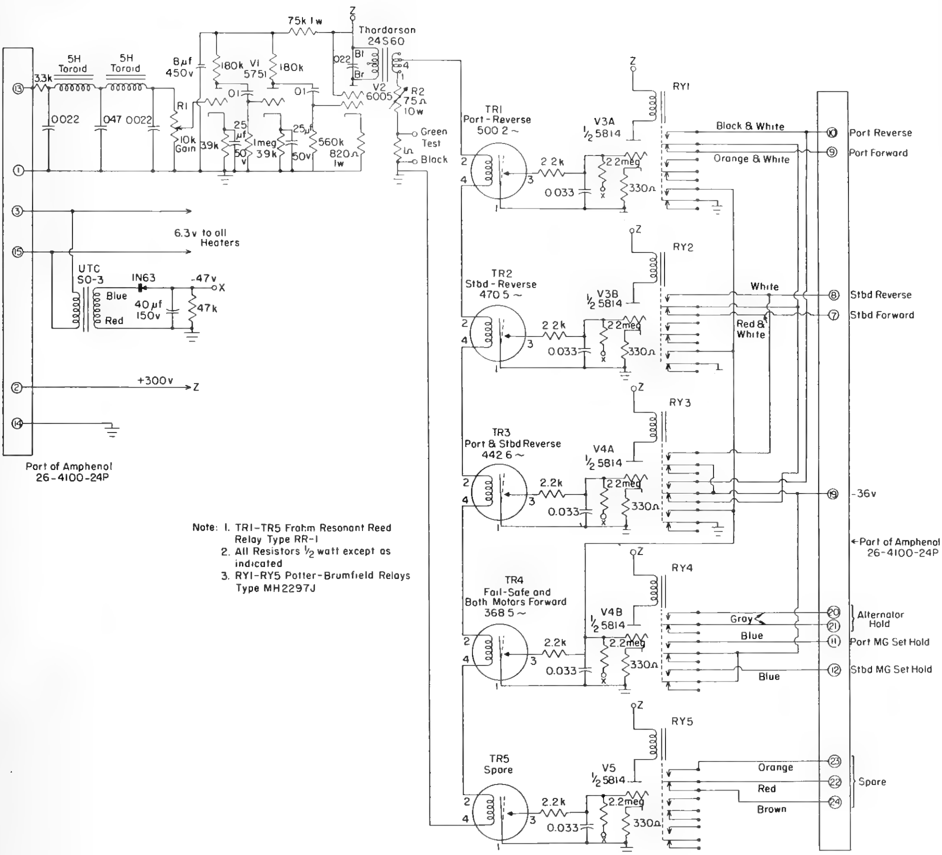
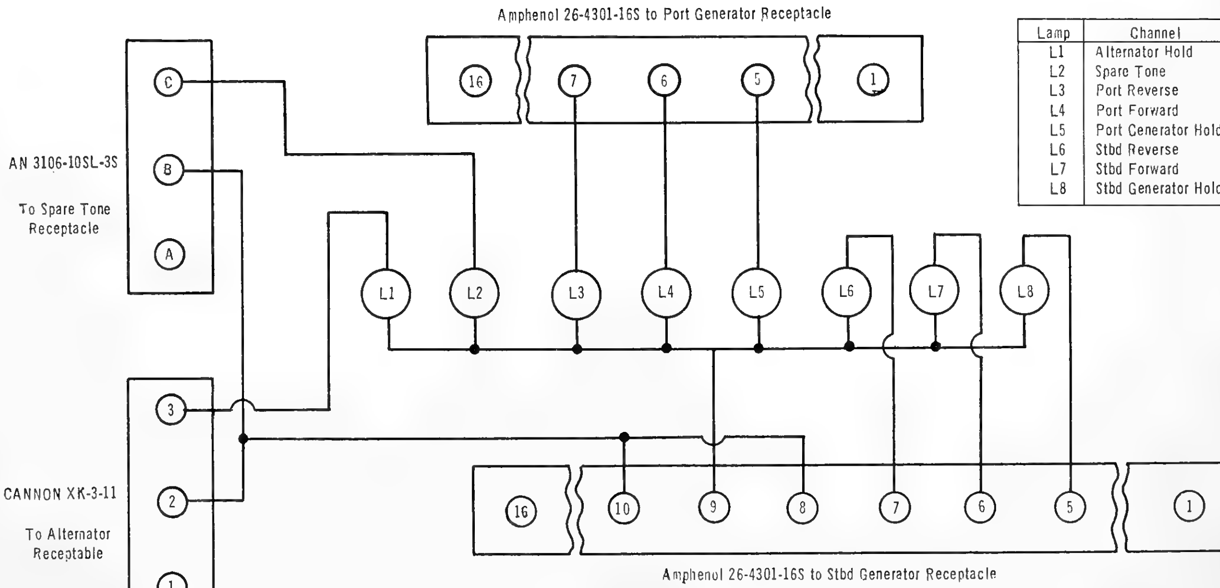


Figure 34 – Tone Detector Type 304-5A, Schematic Diagram



Lamp	Channel
L1	Alternator Hold
L2	Spare Tone
L3	Port Reverse
L4	Port Forward
L5	Port Generator Hold
L6	Stbd Reverse
L7	Stbd Forward
L8	Stbd Generator Hold

Note: All indicator lamps 6.3 v No. 47

Figure 35 – Tone Detector Test Unit, Schematic Diagram

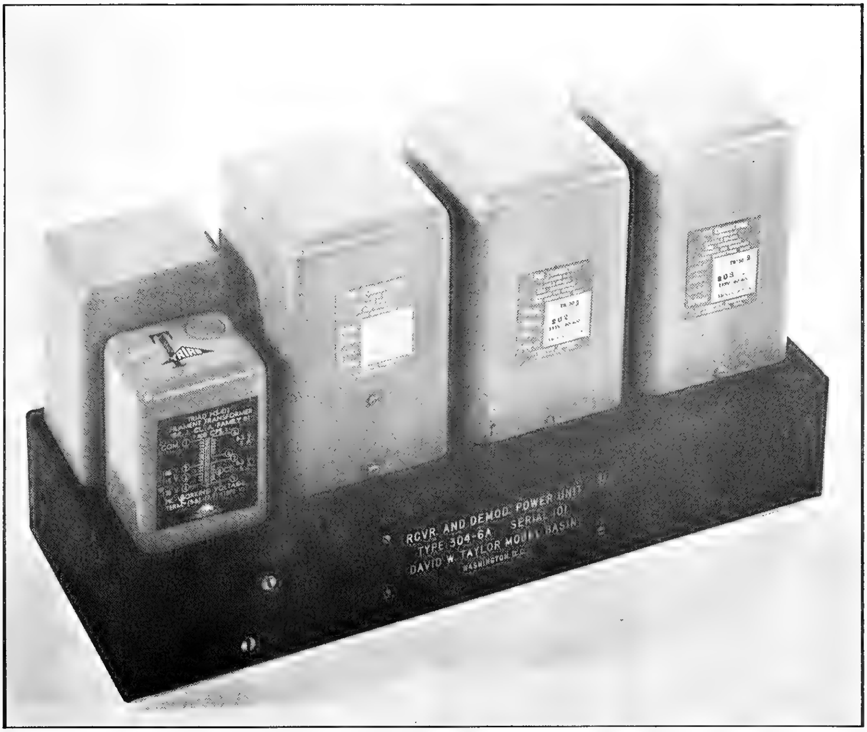


Figure 36 – Receiver and Demodulator Power Unit Type 304-6A, Front Oblique View

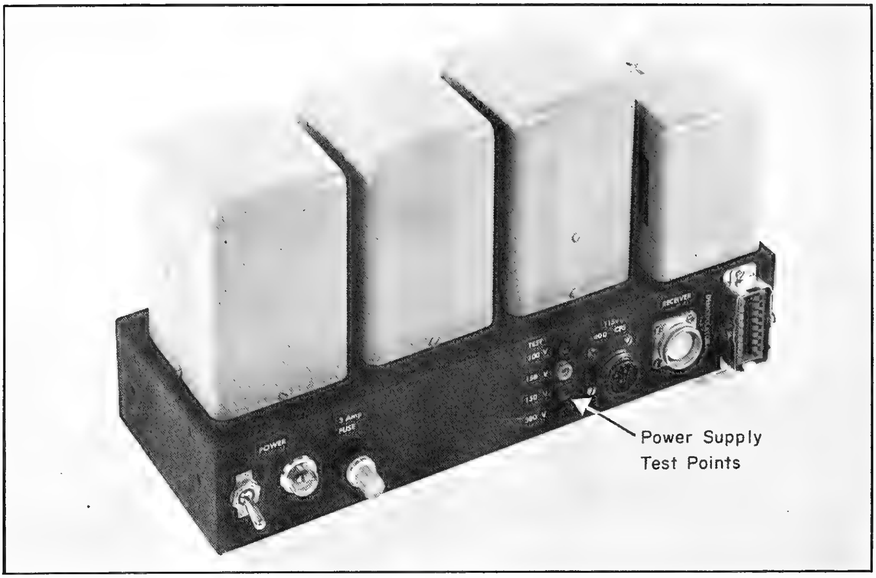


Figure 37 – Receiver and Demodulator Power Unit, Type 304-6A, Rear Oblique View

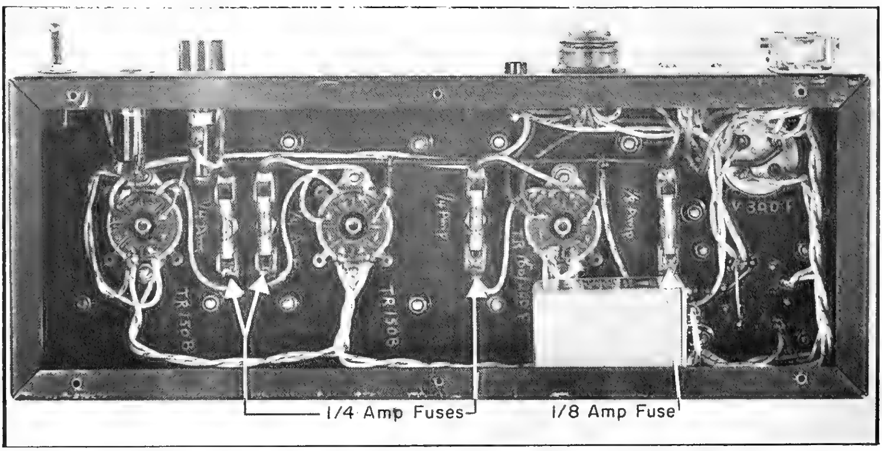


Figure 38 – Receiver and Demodulator Power Unit Type 304-6A, Bottom View

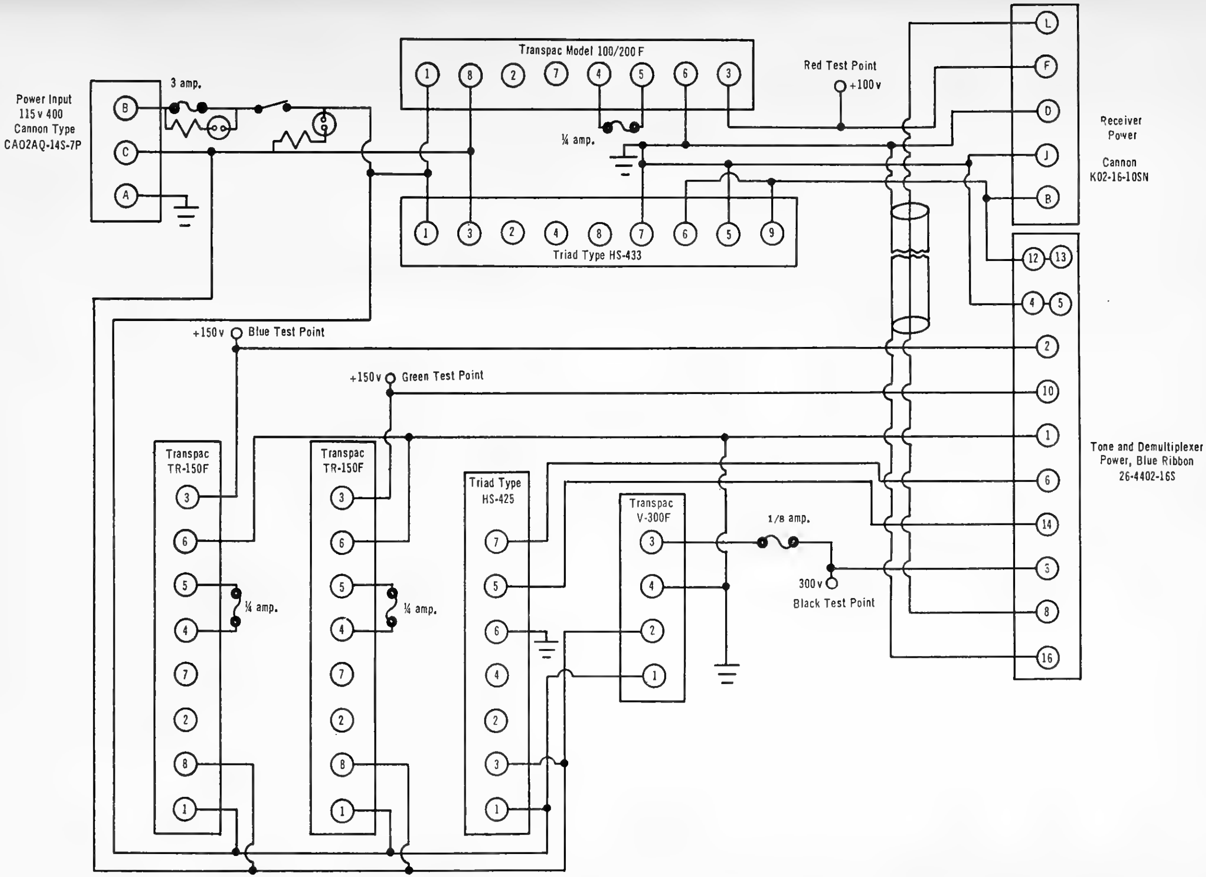


Figure 39 – Receiver and Demodulator Power Unit Type 304-6A, Schematic Diagram

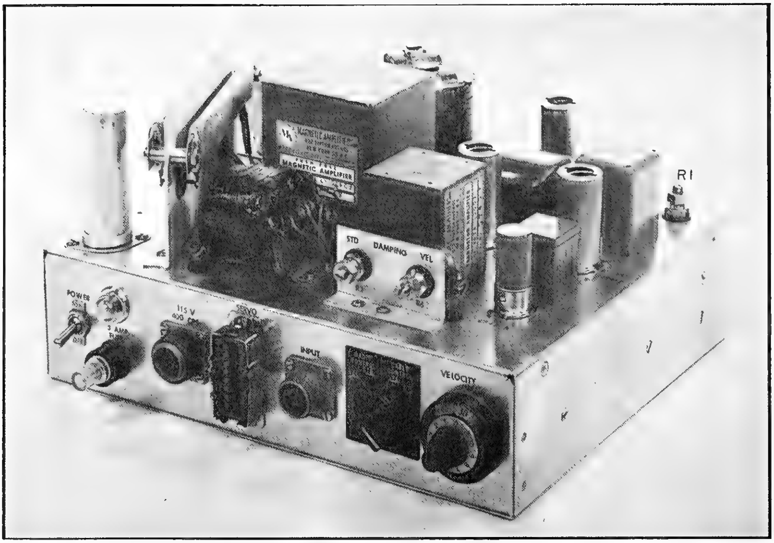


Figure 40 – Servo Amplifier Type 304-7A, Rear Oblique View

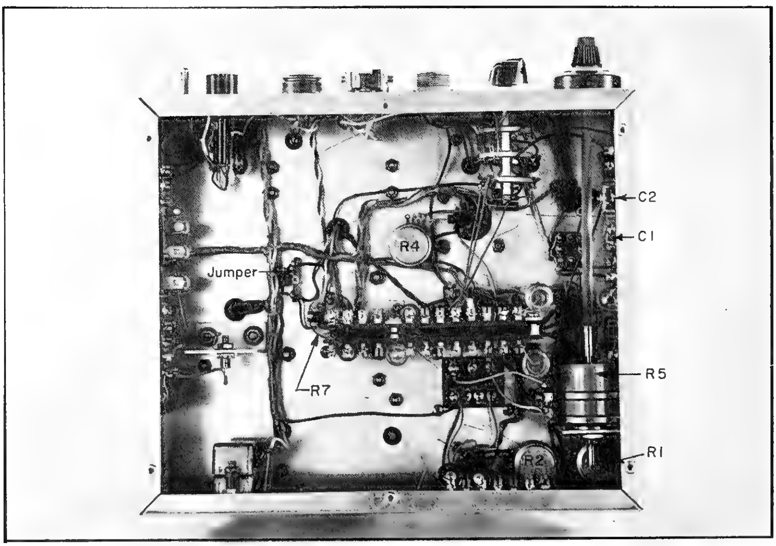
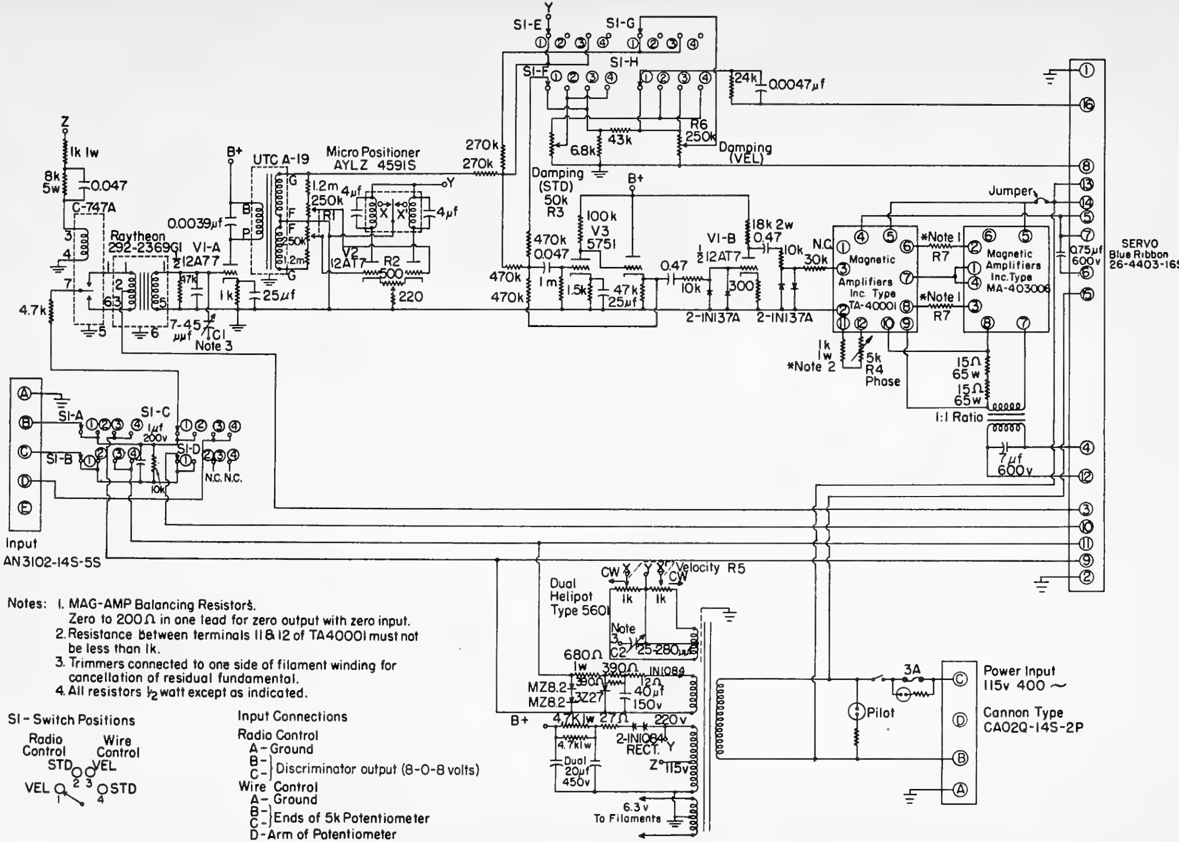


Figure 41 – Servo Amplifier Type 304-7A, Bottom View



Notes: 1. MAG-AMP Balancing Resistors.
Zero to 200Ω in one lead for zero output with zero input.
2. Resistance between terminals 11 & 12 of TA40001 must not be less than 1k.
3. Trimmers connected to one side of filament winding for cancellation of residual fundamental.
4. All resistors ½ watt except as indicated.

S1 - Switch Positions

Radio Control: STD, VEL
Wire Control: VEL, STD

Input Connections

Radio Control
A - Ground
B - } Discriminator output (8-0-8 volts)
C - }

Wire Control
A - Ground
B - } Ends of 5k Potentiometer
C - }
D - Arm of Potentiometer

Figure 42 – Servo Amplifier Type 304-7A, Schematic Diagram

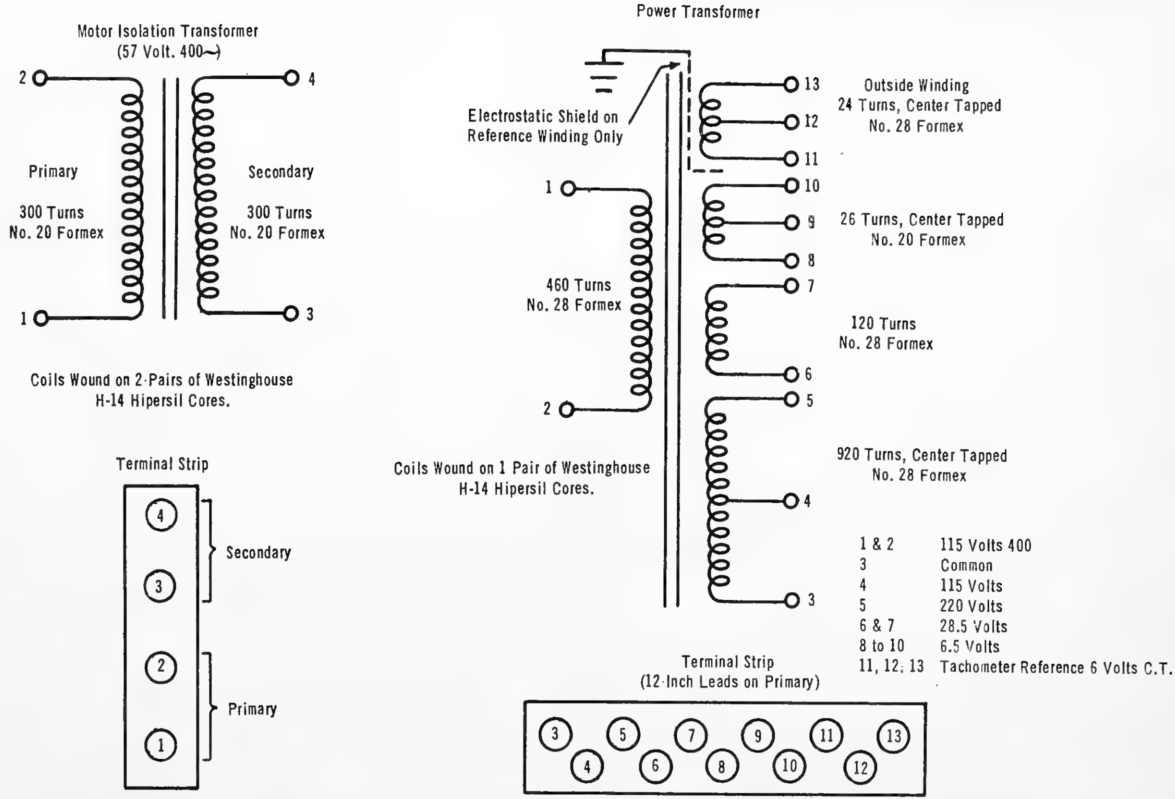


Figure 43 – Servo Amplifier Type 304-7A, Details of Special Transformers

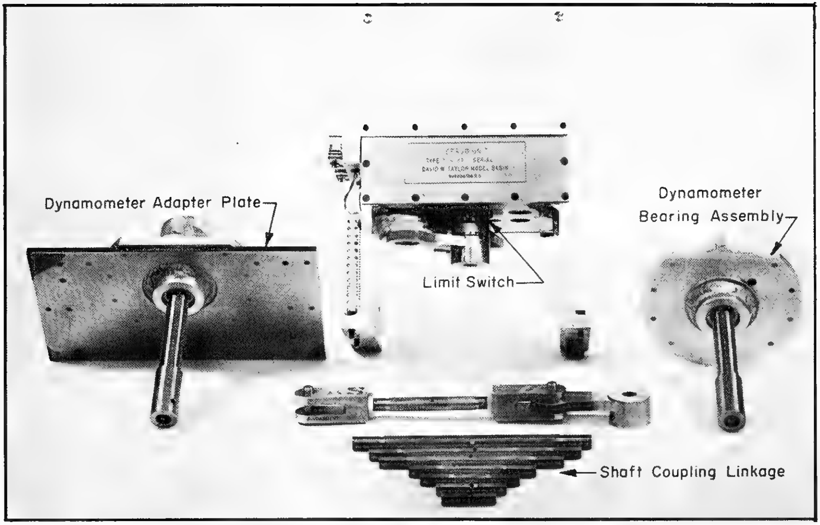


Figure 44 – Servo Unit Type 304-8A, Side View with Attachments

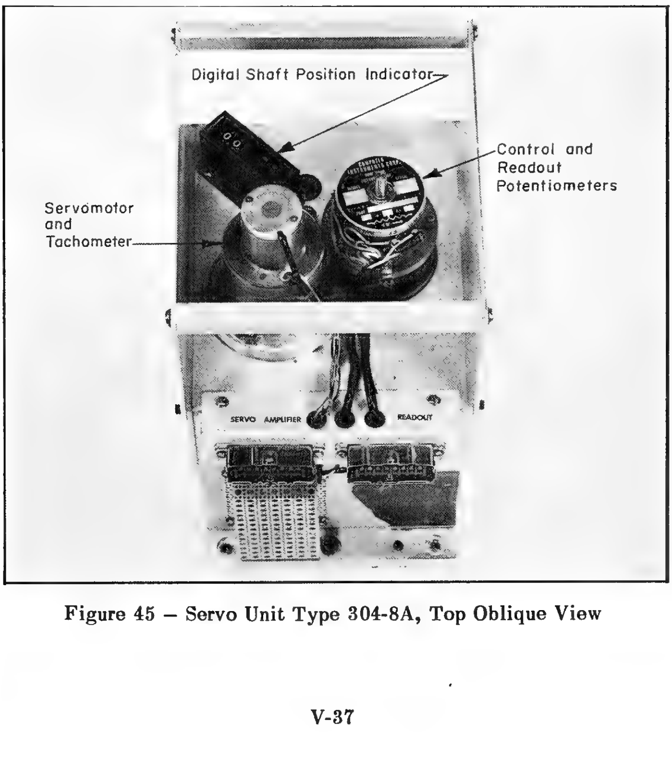


Figure 45 – Servo Unit Type 304-8A, Top Oblique View

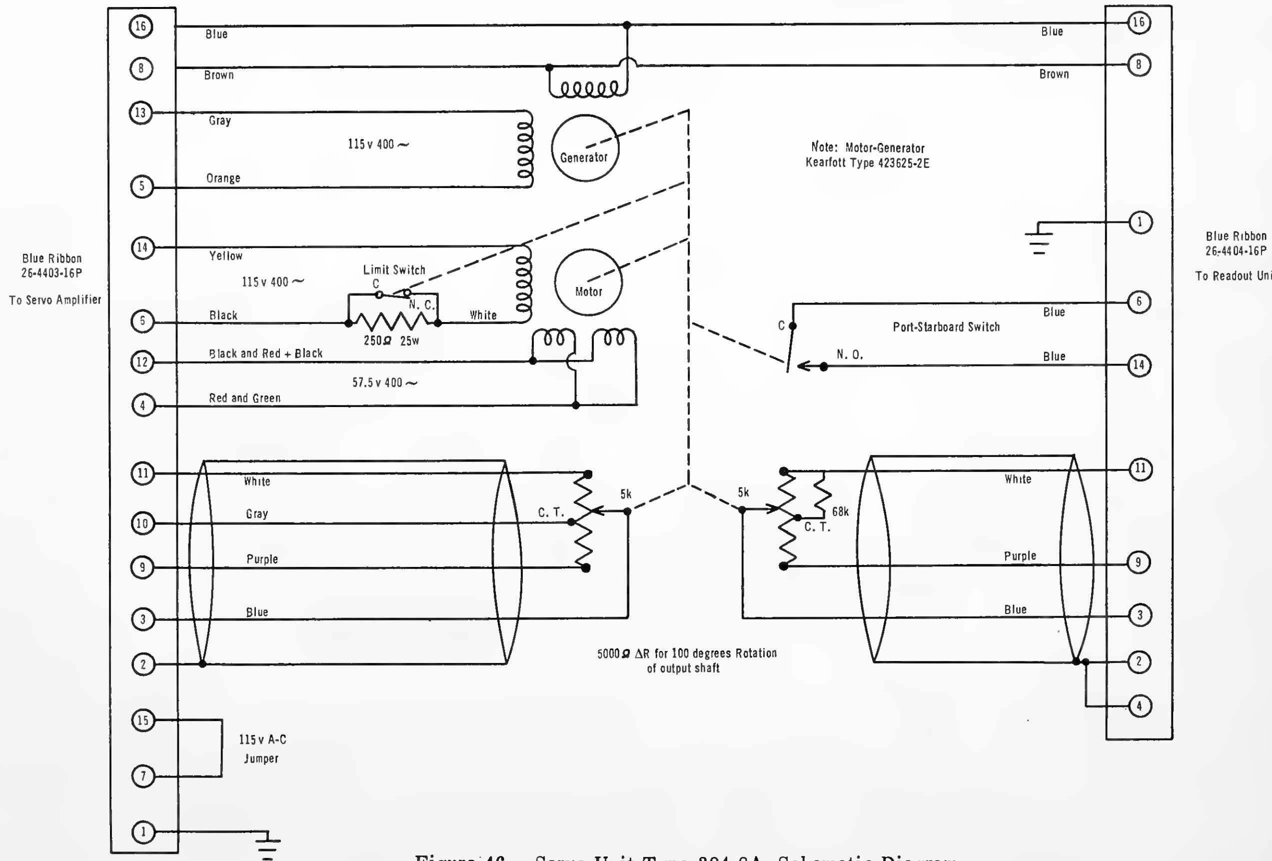


Figure 46 – Servo Unit Type 304-8A, Schematic Diagram

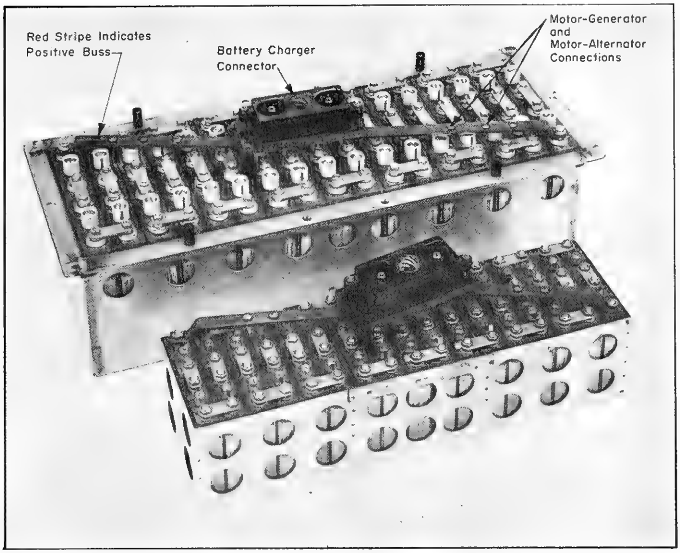


Figure 47 – 10- and 40-Ampere-Hour Batteries, Side View

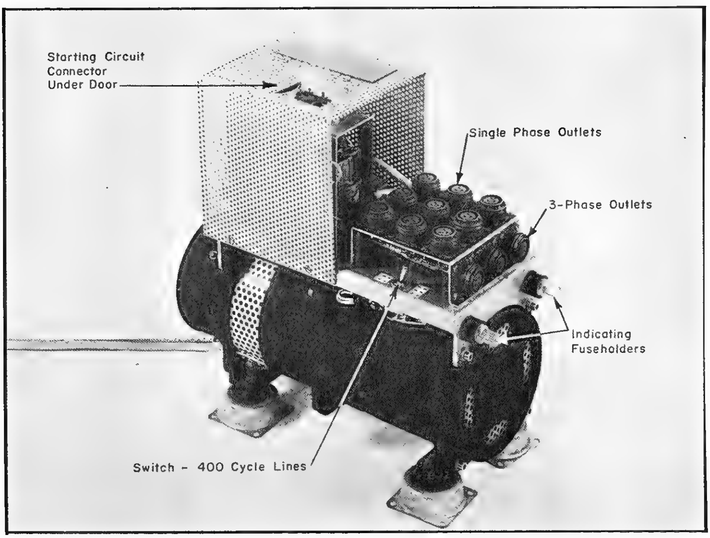


Figure 48 – Motor-Alternator and Control Unit Type 304-9A, Side Oblique View

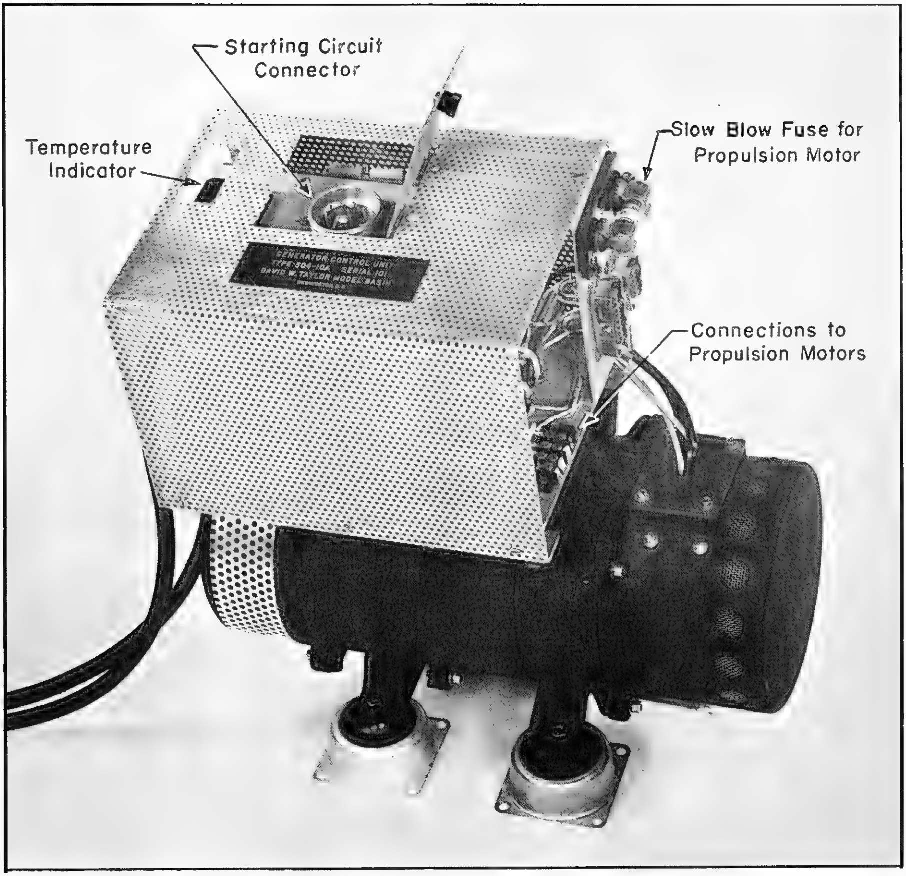
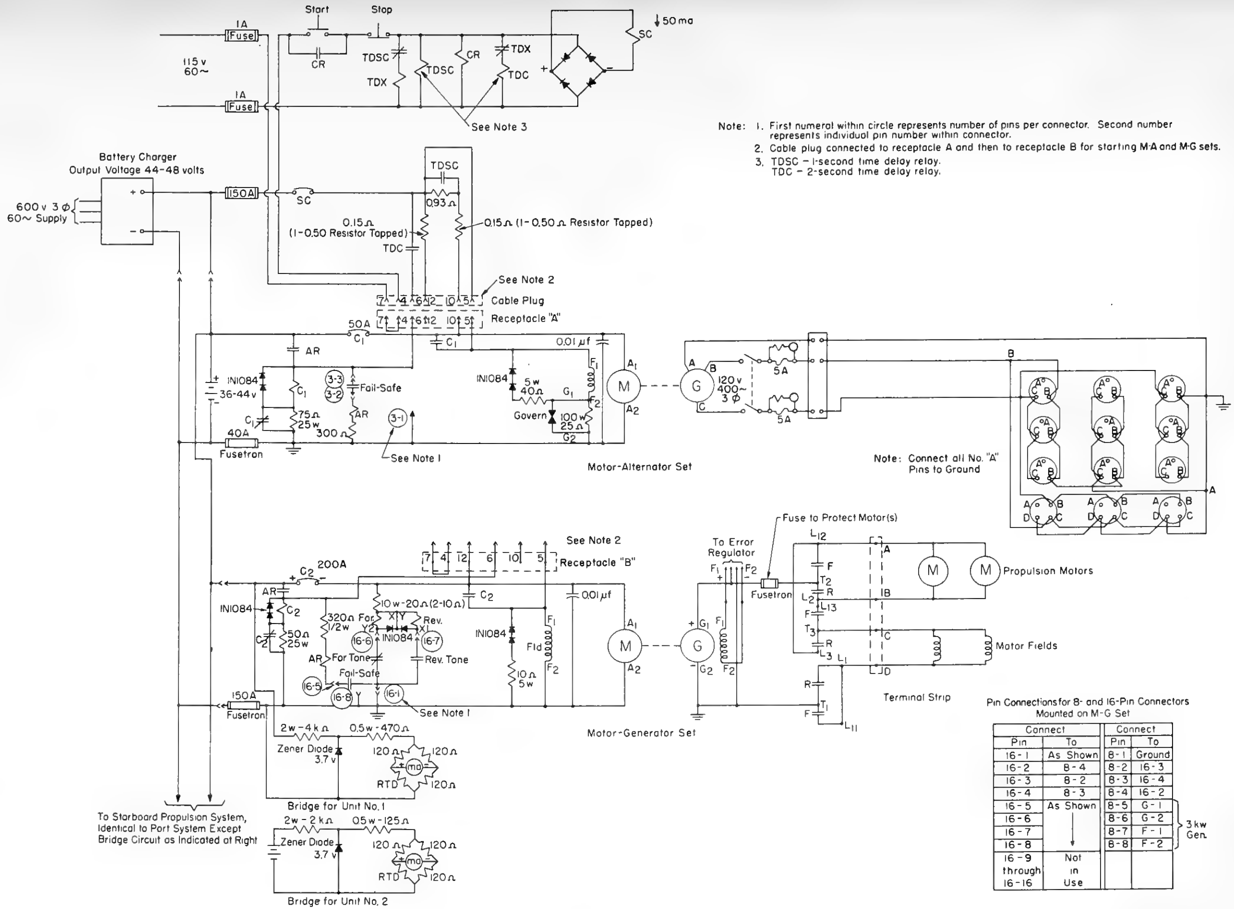


Figure 49 – Motor-Generator and Control Unit Type 304-10A, Side Oblique View



Note: 1. First numeral within circle represents number of pins per connector. Second number represents individual pin number within connector.

2. Cable plug connected to receptacle A and then to receptacle B for starting M-A and M-G sets.

3. TDSC – 1-second time delay relay.
TDC – 2-second time delay relay.

Pin Connections for 8- and 16-Pin Connectors Mounted on M-G Set

Connect		Connect		
Pin	To	Pin	To	
16-1	As Shown	8-1	Ground	
16-2	8-4	8-2	16-3	
16-3	8-2	8-3	16-4	
16-4	8-3	8-4	16-2	
16-5	As Shown	8-5	G-1	3 kw Gen.
16-6	↓	8-6	G-2	3 kw Gen.
16-7	↓	8-7	F-1	3 kw Gen.
16-8	↓	8-8	F-2	3 kw Gen.
16-9 through 16-16	Not in Use			

Figure 50 – Propulsion System, Schematic Diagram

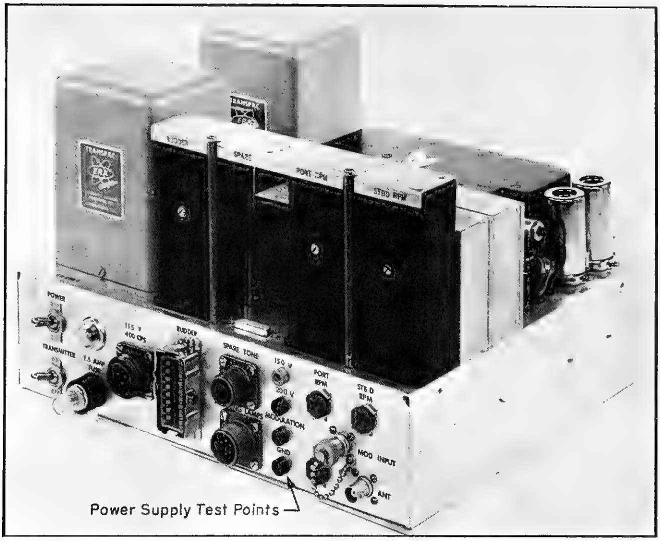


Figure 51 – Readout Unit Type 304-11A, Rear Oblique View

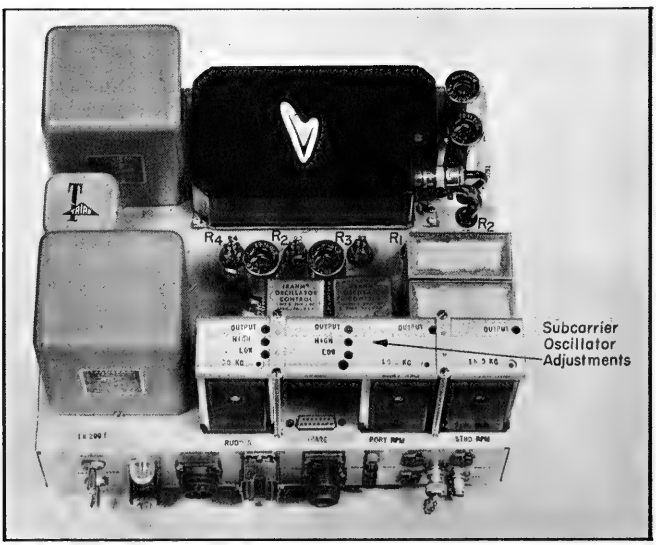


Figure 52 – Readout Unit Type 304-11A, Top View

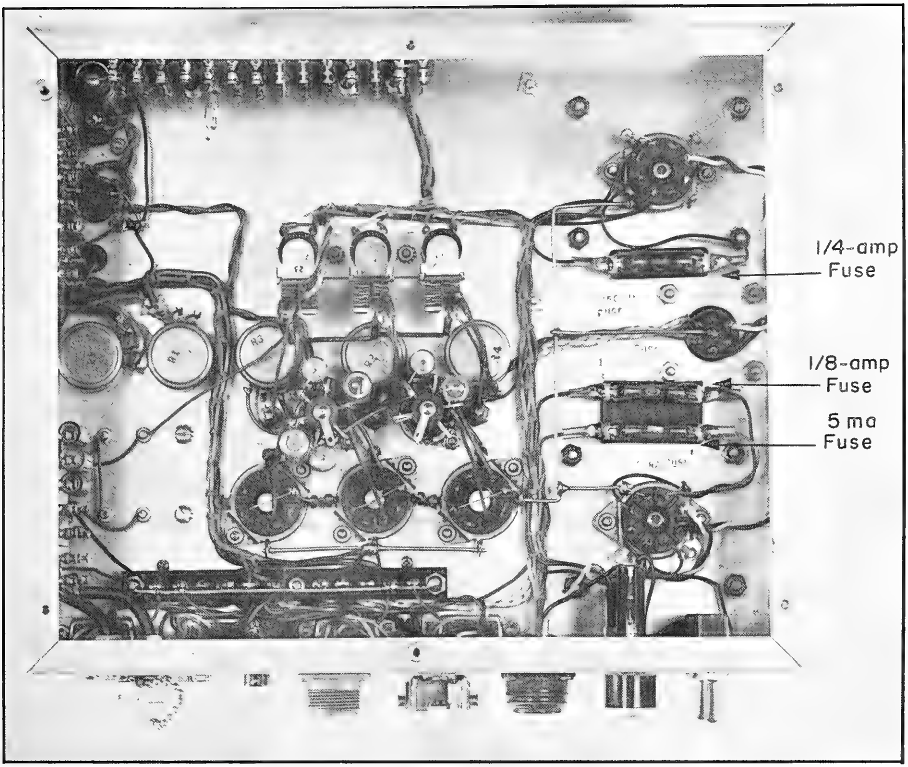


Figure 53 – Readout Unit Type 304-11A, Bottom View

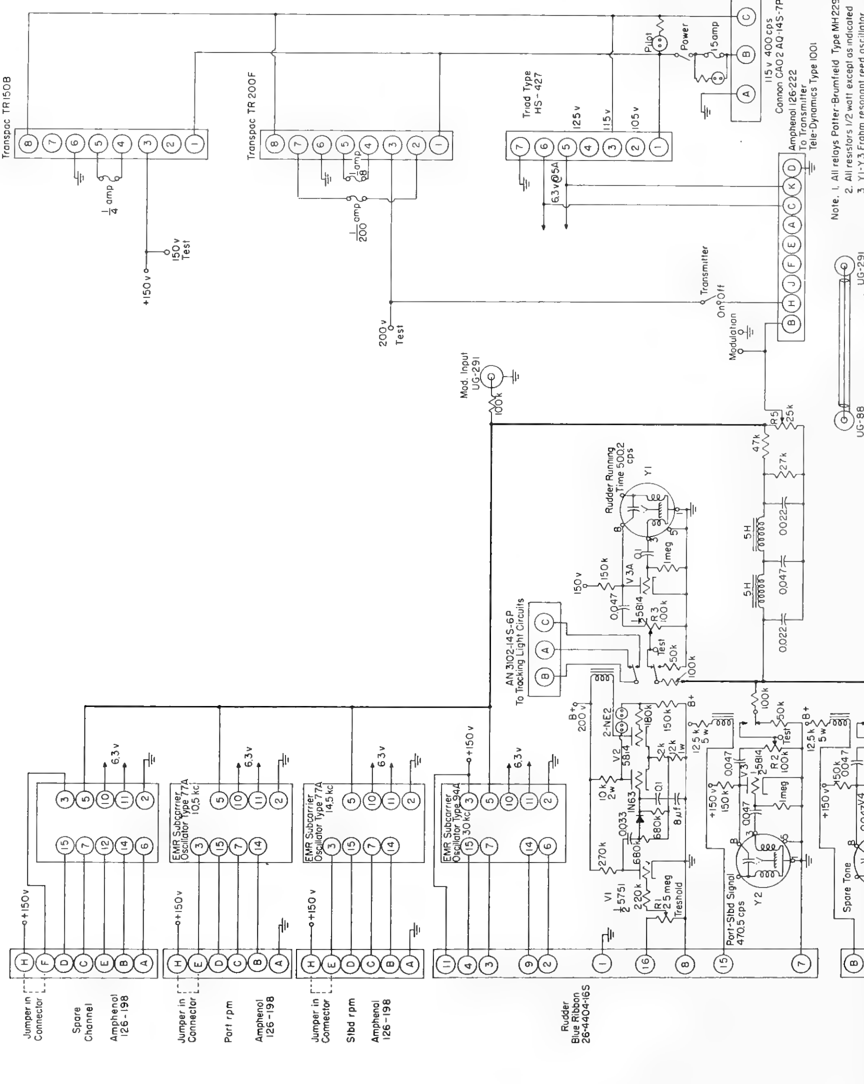


Figure 54 – Readout Unit Type 304-11A, Schematic Diagram

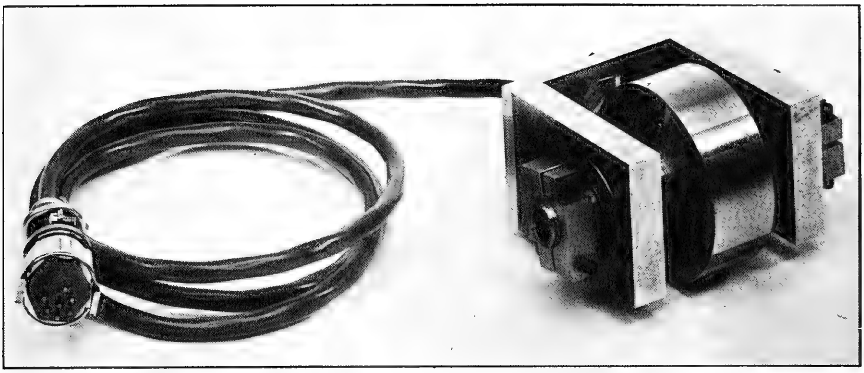


Figure 55 – RPM Pickup Type 304-12A

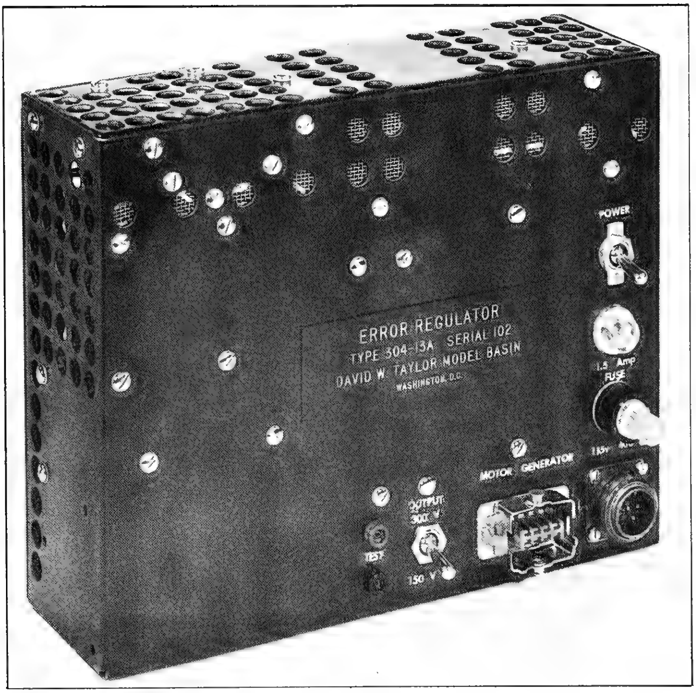


Figure 56 – Error Regulator Type 304-13A, Top View

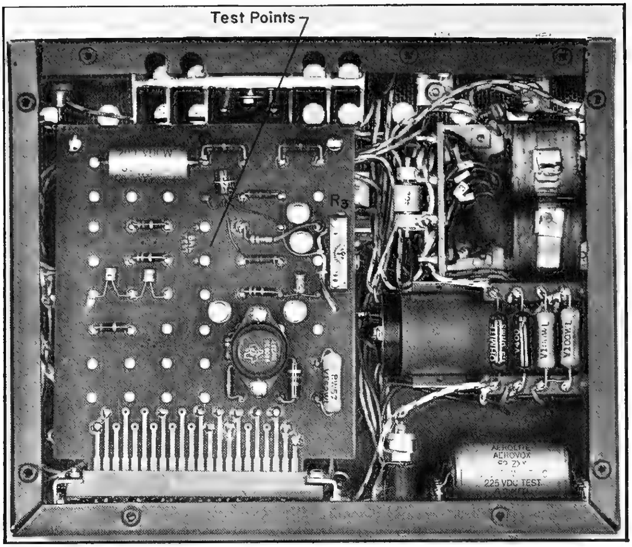


Figure 57 – Error Regulator Type 304-13A, Bottom View

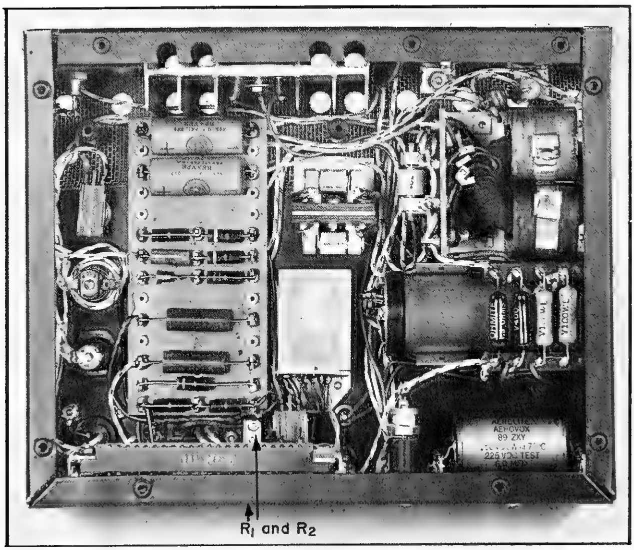


Figure 58 – Error Regulator Type 304-13A, Bottom View without Card

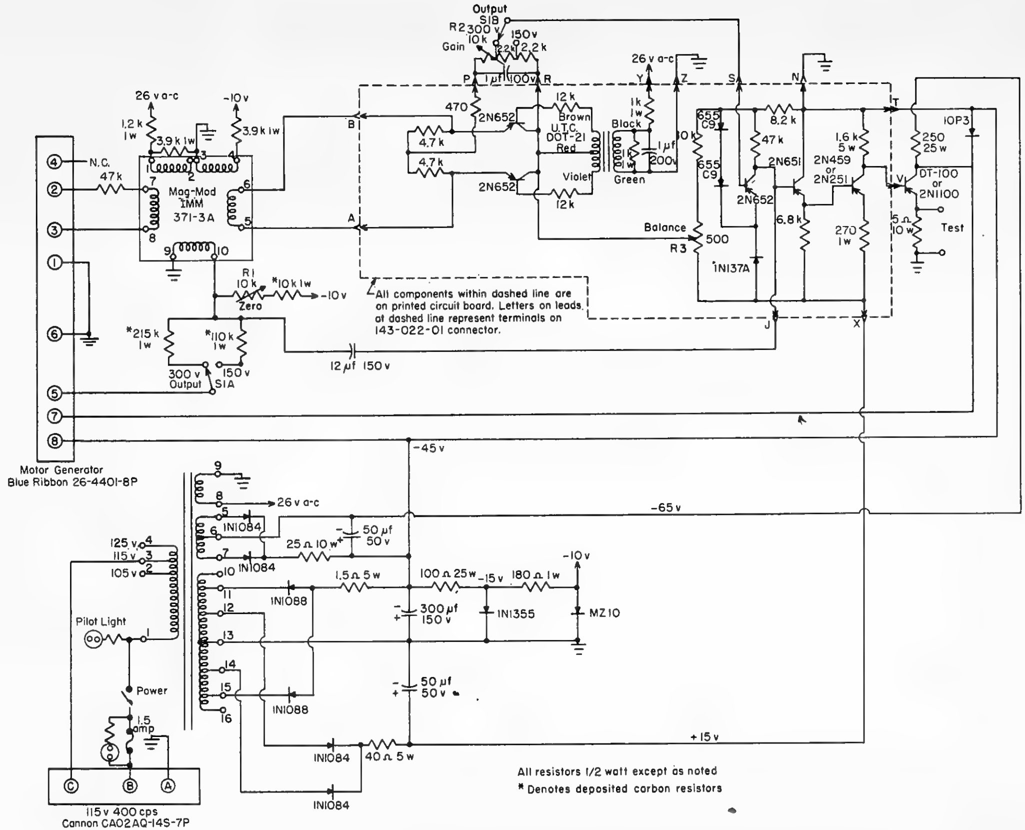


Figure 59 – Error Regulator Type 304-13A, Schematic Diagram

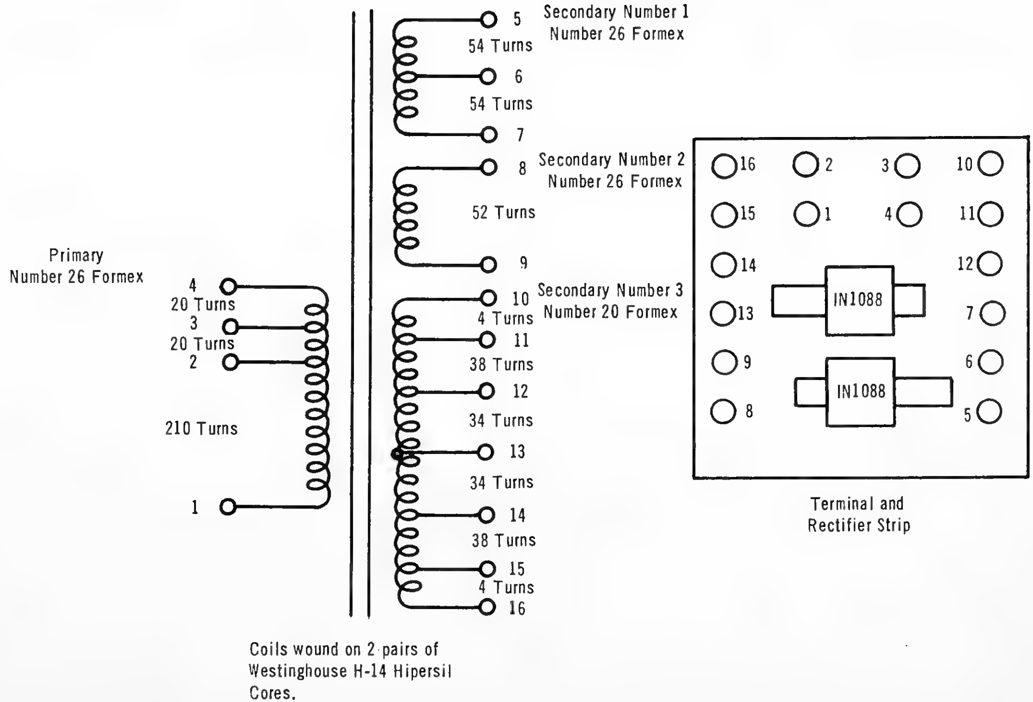


Figure 60 – Error Regulator Type 304-13A, Details of Special Transformer

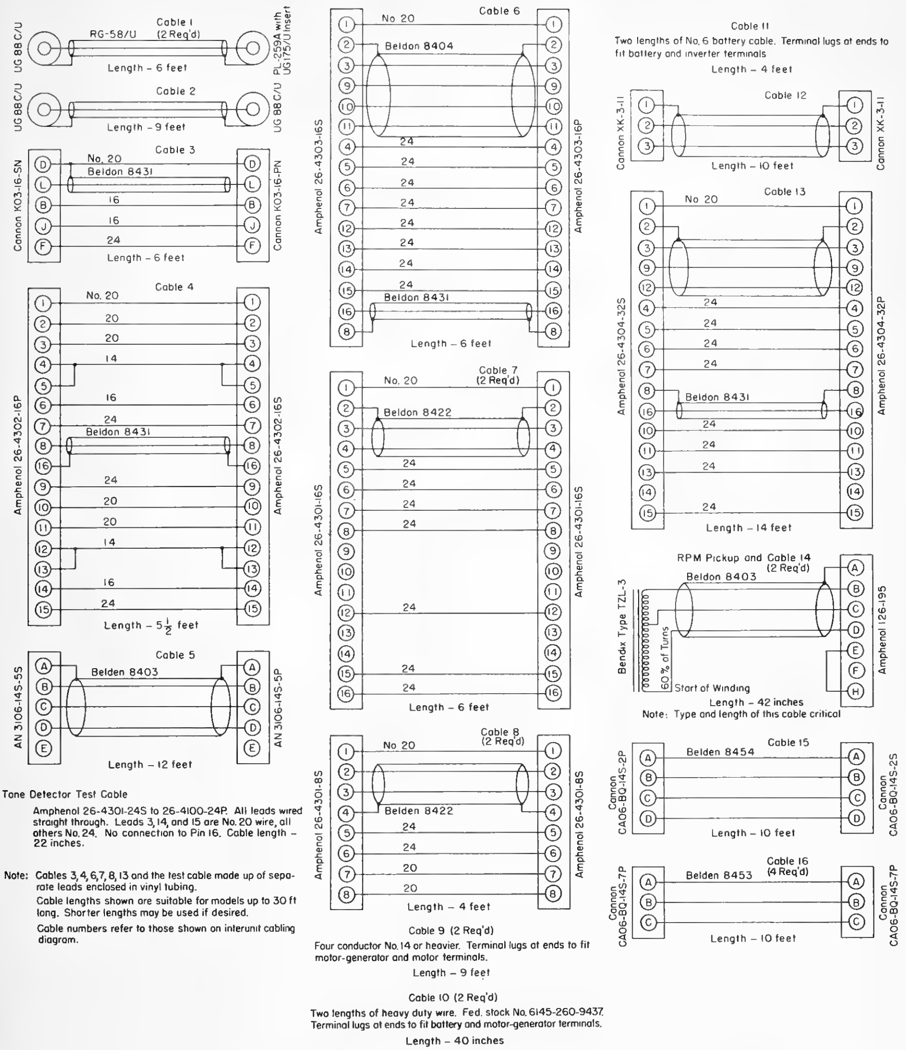


Figure 61 – Cable Details, Schematic Diagram

PART VI – REFERENCES

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5. Instruction Manual, Radio Receiver, Type 2001 Series, Tele-Dynamics, Inc., Philadelphia, Pa.

6. Instruction Manual, Demultiplexer Type 2201C, Tele-Dynamics, Inc., Philadelphia, Pa.

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